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The dispersion phenomena and the influence of temperature on the optic axial angle of Sanidine from the Eifel.

(*With Plates IX and X.*)

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[Read June 15, 1915.]

IN the course of my study of the dispersion phenomena of the felspar group in the Mineralogical Laboratory of the University of Cambridge, Professor Lewis advised me to study the remarkable properties of sanidine from the Eifel, which were first noticed by Des Cloizeaux, and he very kindly placed the mineral sections in the Museum at my disposal. In order to be certain of the material used, application was made to Professor A. Lacroix of Paris, who with the courtesy and generosity characteristic of his countrymen was good enough to send some fragments of the very crystals used by Des Cloizeaux in his classical researches. I tender him my most hearty thanks. My hearty thanks are also due to Mr. A. Hutchinson for his constant help.

Dispersion of the Refractive Indices.

The refractive indices of the Eifel sanidine, for a definite wave-length or for different portions of the spectrum, have been already studied by several authors, either by the method of total reflection or by that of minimum deviation. As the principal indices are liable to differ with the specimen, those of No. 1, a specimen belonging to the Cambridge Museum, were determined in the following way: The refractive indices α and γ for six different wave-lengths were found by the Abbé-Pulfrich total-reflectometer—the instrument used in the determination of the refractive indices of the Rischuna albite.[1] The mean index β could not be thus determined, for the shadows due to the β and γ beams fall too closely together, consequently this index has been computed from the observed values of α and γ combined with the measured angle $2E$.

The data of the crystal No. 1, in Table I, were obtained at a temperature of nearly 19° C. with a section practically perpendicular to the acute bisectrix for $\lambda = 508{\cdot}5\ \mu\mu$. As at this temperature the axial planes were perpendicular to the plane of symmetry for all parts of the spectrum used, the adjustment of the plate was made once for all, and all that was needed was to change the colour of the light.

Table I.[2]

Observed α and γ, and deduced β.

(Temperature 19° C., nearly.)

λ in $\mu\mu$	α	β	γ
486	1·5265	1·5312	1·5312
508·5	1·5249	1·5298	1·5298
535	1·5234	1·5280	1·5280
589 (Na)	1·5206	1·5251	1·5252
644	1·5189	1·5232	1·5233
671	1·5180	1·5225	1·5226

[1] S. Kôzu, 'The dispersion phenomena of albite from Alp Rischuna, Switzerland.' Mineralogical Magazine, 1915, vol. xvii, pp. 189–192.

[2] For comparison are given below the refractive indices of the sanidine from Wehr, Eifel, determined by A. Mülheims (Zeits. Kryst. Min., 1888, vol. xiv, p. 235):—

	α	β and γ
F (486) ...	1·52556 ...	1·53010
b (518) ...	1·52354 ...	1·52813
D (589) ...	1·51984 ...	1·52439
C (656) ...	1·51746 ...	1·52202
B (687) ...	1·51667 ...	1·52100

Dispersion of the Optic Axial Angle and the Optic Axial Plane.

The optic axial angles for different wave-lengths were measured in the two specimens No. 1 and No. 2 by Hutchinson's universal goniometer.[1] Section No. 2 was prepared from one of the Paris specimens examined by Des Cloizeaux, and was about 13 × 7 × 3 mm. It differed from No. 1 inasmuch as at 19° C. the axial plane for long wave-lengths was perpendicular to (010), whilst for short ones it was parallel to (010). Furthermore, the axial angle varied in the different parts of the section for one and the same colour, and this change seemed to take place gradually.

Table II shows the dispersion of the optic axial angle of No. 1 at 19·4° C., and those of four different portions, *b*, *c*, *d*, *e* of section No. 2, at temperatures ranging between 19·4° C. and 19·8° C.

Table II.

E observed in the two specimens No. 1 and No. 2.

λ in μμ	No. 1 ($t.$ = 19·4° C.)	No. 2 ($t.$ = 19·4°–19·8° C.)			
	Axial plane ⊥ (010)				A. P. ∥ (010).
	a	*b*	*c*	*d*	*e*
478	0° 0′	—	—	—	—
486	2 14·7	—	—	—	8°28·3′
508·5	5 12·1	—	—	—	7 4·0
535	7 2·5	—	—	—	5 26·3
542	—	0° 0′	—	—	—
554	7 59·5	2 49·7	—	—	4 4·8
585	—	—	—	—	0 0
589	9 18·7	5 16·2	—	—	—
600	—	—	0° 0′	—	—
610	—	6 11·0	2 2·0	—	—
615	—	—	—	0° 0′	—
644	10 44·8	7 22·3	4 25·2	3 40·0	—
671	11 16·6	8 20·0	5 40·0	5 0	—

The dispersion of the axial plane in the specimen No. 1 was measured by an approximate method with the universal goniometer. The two optic axes for each wave-length were carefully adjusted so as to coincide with the vertical line of the eye-piece, while at the same time the axial angle was bisected by the horizontal wire, the distances of the axes being

[1] A. Hutchinson, 'A universal goniometer.' Mineralogical Magazine, 1911, vol. xvi, pp. 100–108.

determined by a micrometer scale. The deviations of the planes for different wave-lengths were then easily found by rotating the plate. As stated above, the plate was practically perpendicular to the acute bisectrix for $\lambda = 508{\cdot}5\ \mu\mu$, and the axial plane for this wave-length was, in the measurements, taken as standard for the deviations of the other planes. The values measured in air are given in Table III. The correction needed to give the real deviation in the crystal is with sufficient accuracy found by the equation:

$$\sin d_r = \frac{\sin d}{\beta},$$

where d = the observed deviation, d_r = the real one, and β = the mean refractive index.

Table III.

Dispersion of the Optic Axial Plane.

(Temperature 18·8° C. – 19° C.)

λ in $\mu\mu$	Observed deviation (d)	Deduced deviation (d_r)
508·5	0′	0′
535	−15	−9·8
589	−38	−24·9
644	−1° 2	−40·7
671	−1 11	−46·6

The negative sign in the table denotes that on the side pinakoid (010) the angle is measured counter-clockwise from the standard bisectrix. The values of d_r are also those of the dispersion of the elasticity-axes[1] in the symmetrical plane.

THE INFLUENCE OF TEMPERATURE ON THE OPTIC AXIAL ANGLE.

Des Cloizeaux noticed that at ordinary temperature the plane of the optic axes is in most of the crystals perpendicular to that of symmetry, and that the axial angle is small and rapidly diminishes to zero as the temperature is raised. Further, that the axes for blue light closed in first and then at higher temperatures for each colour in turn. As the temperature rises still further the optic axes open out in the symmetry-

[1] Readers interested in the problem of the dispersion of the elasticity-axes will find a theoretical explanation in S. Nakamura, 'Über die Dispersion der optischen Symmetrieachse im durchsichtigen inaktiven monoklinischen Krystall.' Physik. Zeits., 1905, vol. vi, pp. 172–174.

plane, the angle for red being always less than that for blue. He continued his observations up to a temperature of 342·5° C., and has given the corresponding angle for red light for numerous steps. He found that so far the changes were gradual and transitional, and that after a time the crystal returned on cooling to its original condition. He also found that if the plate were raised to the temperature of a porcelain furnace—about 600° C.—the axial plane remained permanently in that of symmetry and that on cooling the angle diminished only to some extent.

In my investigation of these phenomena I have used monochromatic light of seven definite wave-lengths, and the range of temperature has varied from 5° C. to 71° C., the temperature being thus narrowly restricted by the instrumental conditions. The plate was inserted in a cork which exactly fitted in the heating cell and the whole moved together as a plate. The cell was that used by Mr. Hutchinson and Dr. Tutton[1] in the investigation of the changes in gypsum, and was fixed to the rotatory axis in the field of Hutchinson's universal gonio-

Table IV.

486 μμ		50 ·5 μμ		535 μμ		554 μμ		589 μμ		644 μμ		671 μμ	
	E	*t*	*E*	*t*	*E*	*t*	*E*	*t*	*E*	*t*	*E*	*t*	*E*
9°	7°33′	5·4°	8°48′	5·7°	9°45′	5·4°	10°32′	5·7°	11°22′	5·3°	12°29′	5·3°	13°16′
8	4 54	14·8	6 33	14·8	7 53	14·8	8 39	10·0	10 30	14·5	11 6	17·4	11 9
3	4 4	17·3	5 56	17·2	7 21	17·1	8 12	14·2	9 53	17·4	10 45	19·7	10 49
3	3 30	23·3	4 10	23·0	5 58	23·1	6 51	15·3	9 51	19·9	10 13	25·2	10 8
5	0 0	26·1	2 22	26·7	4 41	26·5	5 57	17·0	9 24	25·5	9 26	33·0	8 43
4	3 10	27·5	0 0	30·6	2 55	30·3	4 43	19·9	8 55	32·8	7 53	38·3	7 29
5	5 18	31·3	3 45	33·0	0 0	34·1	3 8	25·0	7 48	38·1	6 38	41·9	6 29
7	5 46	34·8	4 57	35·3	2 49	37·0	0 0	26·2	7 38	41·7	5 35	47·4	5 1
6	6 40	40·5	6 34	39·8	4 44	39·0	2 13	32·3	5 50	44·2	4 42	51·6	3 4
1	8 12	45·5	7 49	45·5	6 25	45·2	5 11	35·5	4 40	47·3	3 34	53·8	0 0
6	9 15	52·5	9 22	52·3	8 6	51·3	7 3	39·5	3 24	51·7	0 0	57·5	3 53
0	10 25	55·3	9 43	57·6	8 59	57·6	8 14	42·0	2 20	53·2	2 42	60·4	4 27
				63·8	10 8	63·4	9 19	43·5	0 0	55·4	4 7	63·7	5 40
						68·7	10 13	45·3	2 38	57·4	4 32	66·2	6 30
								47·5	3 34	60·3	5 30	71·5	7 38
								51·5	5 20	63·5	6 30		
								55·0	6 13	66·5	7 15		
								60·5	7 28	71·5	8 47		
								66·6	8 55				
								71·6	9 48				

[1] A. Hutchinson and A. E. H. Tutton, 'On the temperature of optical uniaxiality in gypsum.' Mineralogical Magazine, 1912, vol. xvi, pp. 257–263.

meter. The observed angle is $2E$. In the experiment the sides of the cell and the crystal plate should all be parallel to one another, and also to the axis of the graduated circle. The adjustments are difficult and cannot be made with much accuracy, and the faults arising from this cause are the main source of the errors in the observations. For the temperatures and wave-lengths stated the observed values of E are given in Table IV (p. 241).

The variation with the temperature of E for each wave-length is graphically represented in Plate IX, which is a reduction of a diagram plotted on millimeter paper. In the diagram 5 mm. along the abscissae represent 1° C., and 10 mm. along the vertical ordinate an angle of 1°. The single circlets give actual determinations when the plate lies in the cell, the double circlets give those in which the plate alone was used. The black dots are points on the curves which correspond to temperatures differing from that of the zero-point of the curve by 10° C. and 15° C. The continuous curve (with λ constant) may be denoted as the (E t) curve. Each of them has one point of inflexion, which corresponds to the zero position of the axial angle. On the opposite sides of this point the optic axial planes are perpendicular to one another, the plane at lower temperatures being at right angles to that of crystallographic symmetry, and at higher temperatures parallel to it. In the former position of the plane, the angle diminishes as the temperature rises, while in the latter the angle increases with the temperature.

Assuming the refractive indices to be linear functions of the temperature, Pockels[1] has shown that for a *rhombic* crystal the curve connecting temperature and axial angle (when the latter is small) is a parabola having its vertex at the zero-point of E. In the Eifel sanidine the displacement of the acute bisectrix for each colour at different temperatures was tested for the case where $\lambda = 589\ \mu\mu$. It was found to be so very small as to be negligible within the range of temperature employed, and the same has been assumed in every other case. The symmetry-axis of the crystal is for every colour necessarily a fixed principal axis. Hence as long as one colour only is considered, the portion of the (E t) curve on each side of the uniaxiality point should also be a parabola. Within the limits of error in the observations they prove to be so; and each portion can be readily shown to lie between the two parabolas:— $E_{\prime}^{2} = -3{\cdot}3\ t$, and $E_{//}^{2} = -3{\cdot}6\ t$; the negative sign being introduced to correspond with the diagram. These two parabolas are drawn in the

[1] F. Pockels, 'Lehrbuch der Kristalloptik,' 1906, p. 454.

figure, the zero-points having been placed arbitrarily at 65° C. and 70° C. The values of E_r and E_v for different decrements of temperature are given in Table V, and for the sake of comparison their values have been read from the two parabolas at temperatures corresponding with those at which measurements of E were made. The three sets of values are given in Table VI (pp. 244–5). The accuracy attainable in the readings from the diagram is within the limits $\pm 6'$. With few exceptions (marked by stars) the observed values of E fall between the corresponding values of E_r and E_v. Hence in the several curves extremities of the ordinates corresponding to a definite increment or decrement of temperature should lie very approximately on a straight line parallel to the line of abscissae. That this is the case may be seen from the black dots which give ordinates for temperatures differing from those of the zero-points by 10° C. and 15° C. This may be put in another way; viz. that all the curves are, within the limits of accuracy attainable, identical, and can by a mere translation along the line of abscissae be superposed the one on the other.

To test the phenomena further, Plate X, fig. 1 has been drawn, in which the abscissae are wave-lengths, the ordinates E, and the temperature corresponding to each of the curves is that indicated at its extremity. The curves may be distinguished from the former ones by calling them the $(E\lambda)$ curves. They have been obtained from Plate IX, by plotting off the value of E corresponding to definite values of λ and t. As in Plate IX, the double circlets give actual observations on specimens Nos. 1 and 2, when the plate alone was used. The crosses correspond

Table V.

t	E_r	E_v
1°	1·82°	1·90°
2	2·57	2·68
5	4·06	4·24
8	5·10	5·40
10	5·75	6·00
15	7·04	7·35
20	8·03	8·48
25	9·08	9·49
30	9·95	10·39
35	10·75	11·23
40	11·49	12·00
45	12·19	12·73

Table VI.

$\lambda = 486\ \mu\mu$				$\lambda = 508{\cdot}5\ \mu\mu$			
t	$E_{/}$	E	$E_{//}$	t	$E_{/}$	E	$E_{//}$
5·9°	7°24′	7°33′	7°45′	5·4°	8°33′	8°48′	8°57′
14·8	4 54	4 54	5 18	14·8	6 27	6 33	6 45
17·3	4 6	4 4*	4 21	17·3	5 48	5 56	6 6
19·3	3 15	3 30*	3 24	23·3	3 39	4 10*	3 54
22·5	0 0	0 0	0 0	26·1	2 10	2 22*	2 20
25·4	3 6	3 10	3 12	27·5	0 0	0 0	0 0
30·5	5 6	5 18	5 24	31·3	3 30	3 45*	3 42
31·7	5 30	5 46	5 48	34·8	4 52	4 57	5 9
34·6	6 21	6 40	6 40	40·5	6 30	6 34	6 51
41·1	7 48	8 12	8 12	45·5	7 39	7 49	8 3
45·6	8 42	9 15*	9 9	52·5	9 18	9 22	9 42
52·0	9 51	10 25*	10 21	55·3	9 36	9 43	10 0

$\lambda = 535\ \mu\mu$				$\lambda = 554\ \mu\mu$			
t	$E_{/}$	E	$E_{//}$	t	$E_{/}$	E	$E_{//}$
5·7°	9°30′	9°45′	9°57′	5·4°	10°12′	10°32′	10°42′
14·8	7 42	7 53	8 6	14·8	8 30	8 39	8 57
17·2	7 24	7 21*	7 48	17·1	8 2	8 12	8 30
23·0	5 45	5 58	6 0	23·1	6 48	6 51	7 3
26·7	4 33	4 41	4 48	26·5	5 54	5 57	6 9
30·6	2 45	2 55	2 57	30·3	4 42	4 43	4 57
33·0	0 0	0 0	0 0	34·1	3 6	3 8	3 15
35·0	2 34	2 49*	2 41	37·0	0 0	0 0	0 0
39·8	4 42	4 44	4 57	39·0	2 34	2	2 41
45·5	6 24	6 25	6 42	45·0	5 10	5 11	5 27
52·3	7 54	8 6	8 21	51·3	6 54	7 3	7 9
57·6	9 0	8 59*	9 27	57·6	8 12	8 14	8 39
63·8	10 6	10 8	10 33	63·4	9 20	9 19	9 45
				68·7	10 12	10 13	10 45

Table VI (cont.).

$\lambda = 589\ \mu\mu$				$\lambda = 644\ \mu\mu$			
t	$E_{'}$	E	$E_{''}$	t	$E_{'}$	E	$E_{''}$
5·7°	11°12′	11°22′	11°39′	5·3°	12°27′	12°29′	12°57′
10·0	10 30	10 30	11 0	14·5	11 6	11 6	11 36
15·3	9 39	9 51	10 6	17·4	10 39	10 45	11 9
17·0	9 21	9 24	9 48	19·9	10 12	10 13	10 42
19·9	8 51	8 55	9 15	25·5	9 15	9 26	9 45
25·0	7 45	7 48	8 12	32·8	7 50	7 53	8 15
26·2	7 33	7 38	7 54	38·1	6 45	6 38*	7 0
32·3	6 3	5 50*	6 21	41·7	5 45	5 35*	6 0
35·5	5 6	4 40*	5 24	44·2	4 57	4 42*	5 12
39·5	3 33	3 24*	3 48	47·3	3 42	3 34	4 0
42·0	2 15	2 30*	2 20	51·7	0 0	0 0	0 0
43·5	0 0	0 0	0 0	53·2	2 15	2 42*	2 20
45·3	2 24	2 38*	2 33	55·4	3 30	4 7*	3 39
47·5	3 33	3 34	3 48	57·4	4 18	4 32	4 33
51·5	5 6	5 20	5 24	60·3	5 18	5 30	5 36
55·0	6 9	6 13	6 27	63·5	6 15	6 30	6 33
60·5	7 27	7 28	7 48	66·5	7 0	7 15	7 18
66·6	8 42	8 55	9 9	71·5	8 0	8 47*	8 24
71·6	9 36	9 49	10 3				

$\lambda = 671\ \mu\mu$			
t	$E_{'}$	E	$E_{''}$
5·3°	12°45′	13°16′	13°18′
17·4	10 48	11 9	11 30
19·7	10 36	10 49	11 6
25·2	9 42	10 8	10 12
33·0	8 15	8 43	8 42
38·3	7 6	7 29	7 30
41·9	6 15	6 29	6 33
47·4	4 36	5 1*	4 48
51·6	2 39	3 4*	2 48
53·8	0 0	0 0	0 0
57·5	3 30	3 53*	3 39
60·4	4 39	4 27*	4 54
63·7	5 42	5 40*	5 57
66·2	6 23	6 30	6 42
71·5	7 35	7 38	7 57

to equal differences of abscissae measured from the zero-points, and lie very nearly on straight lines, which, if the curves of Plate IX were strictly equal parabolas, should be parallel to the line of abscissae. They are, however, very appreciably inclined to it and to one another.

Another curve, U, in Plate IX, shows the relation of uniaxiality of the crystal, the abscissae giving the temperature, and the ordinates the wave-lengths. Its empirical formula is:

$$t = 0{\cdot}2390\,\lambda - 0{\cdot}0003\,\lambda^2,$$

the origin of co-ordinates being at $t = 22{\cdot}5°$ C. and $\lambda = 486\,\mu\mu$.

The Dispersion Formula for the Optic Axial Angle.

To test the assumption that the dispersion of the optic axial angle agrees with the equation:

$$\sin E = \sqrt{P + \frac{Q}{\lambda^2}}. \quad \ldots\ldots\ldots \quad (1)$$

the values of P and Q for definite values of λ were obtained from the two sets of observation of E on the specimens Nos. 1 and 2, which are given in columns a and b in Table II. After reduction by the method of least squares, they are:

for a, $P_1 = 0{\cdot}078744$, $Q_1 = -18236{\cdot}4$
for b, $P_2 = 0{\cdot}059173$, $Q_2 = -17498{\cdot}2$

Table VII gives the measured and computed values for different values of λ, and the divergences between the observed and computed angles.

Table VII.

λ in $\mu\mu$	E of No. 1 (curve a)			E of No. 2 (curve b)		
	Computed.	Observed.	Difference.	Computed.	Observed.	Difference.
478	—	0° 0′	—	—	—	—
481	0° 0′	—	—	—	—	—
486	2 14·7	2 55·0	− 40·3′	—	—	—
508·5	5 12·1	5 8·5	+ 3·6	—	—	—
535	7 2·5	6 53·5	+ 9·0	—	—	—
542	—	—	—	—	0° 0′	—
544	—	—	—	0° 0′	—	—
554	7 59·5	7 51·0	+ 8·5	2 40·3	2 49·7	− 9·4′
589	9 18·7	9 8·5	+ 10·2	5 21·7	5 16·2	+ 5·5
610	—	—	—	6 19·7	6 11·0	+ 8·7
644	10 44·8	10 41·5	+ 3·3	7 29·3	7 22·3	+ 7·0
671	11 16·6	11 9·0	+ 7·6	8 11·5	8 20·0	− 8·5

The observed and computed values, plotted on millimeter paper, are shown in Plate X, fig. 2, the abscissae measuring the wave-length in $\mu\mu$, and the ordinates E ($1° = 10$ mm.) being measured from a horizontal line supposed to pass through the acute bisectrix for all wave-lengths. It will be seen from the table and figure that the observed and computed values agree well together—the only serious divergence in E being that in the immediate neighbourhood of the point $E = 0°$. The zero-point of the computed ordinate is in each case displaced down the spectrum—to an extent of $3\,\mu\mu$ in curve a, and $2\,\mu\mu$ in curve b. With the exception of this portion of the curves, equation (1) may be accepted as correct.

Instead of equation (1) Pockels[1] uses:

$$\sin E = \frac{a}{\sqrt{\gamma^2 - a^2}} \sqrt{A_3 - A_2 + \frac{B_3 - B_2}{\lambda^2}}. \quad . \; . \; . \quad (1^*)$$

In obtaining this equation he assumes E to be always small, the fraction $\frac{a}{\sqrt{\gamma^2 - a^2}}$ to be constant, and that the dispersion of the refractive indices is given by

$$\mu_n^2 = A_n + \frac{B_n}{\lambda^2}. \quad . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

Equations (1) and (1*) are identical, if

$$\left.\begin{aligned} P &= \frac{a^2}{\gamma^2 - a^2}(A_3 - A_2) \\ Q &= \frac{a^2}{\gamma^2 - a^2}(B_3 - B_2) \end{aligned}\right\} \quad . \; . \; . \; . \; . \; . \; . \quad (3)$$

To prove the truth of equations (3) in detail is not easy without very accurate data of the refractive indices. But the following results show that the variation of $\frac{a^2}{\gamma^2 - a^2}$ may be neglected in the determination of E.

Let $\qquad \frac{a}{\sqrt{\gamma^2 - a^2}} = x \qquad$ for $\lambda = 486\,\mu\mu$,

and $\qquad \frac{a_1}{\sqrt{\gamma_1^2 - a_1^2}} = x + \Delta x$ for $\lambda = 671\,\mu\mu$;

these wave-lengths being the extremes taken in the series of the determinations of the refractive indices a and γ.

[1] F. Pockels, loc. cit., p. 71.

For $\lambda = 486\mu\mu$, $\quad a = 1{\cdot}5265, \quad \gamma = 1{\cdot}5312,$

$$\therefore \quad x = 12{\cdot}78.$$

For $\lambda = 671\mu\mu$, $\quad a_1 = 1{\cdot}5180, \quad \gamma_1 = 1{\cdot}5226,$

$$\therefore \quad x + \Delta x = 12{\cdot}91.$$

Hence $$\Delta x = 0{\cdot}13.$$

The change in x is therefore only 1/100 of its value.

Again, from the equation

$$\sin E = a\sqrt{\frac{\gamma^2-\beta^2}{\gamma^2-a^2}},$$

we obtain

$$\sin E' = x\sqrt{\gamma^2-\beta^2} \quad \text{for } \lambda = 486\mu\mu;$$

$$\sin E'' = (x+\Delta x)\sqrt{\gamma_1^2-\beta_1^2} \quad \text{for } \lambda = 671\mu\mu.$$

Now put $$\sin E_0'' = x\sqrt{\gamma_1^2-\beta_1^2}.$$

$$\therefore \quad \sin E'' - \sin E_0'' = \Delta x\sqrt{\gamma_1^2-\beta_1^2}.$$

And writing ΔE for $E'' - E_0''$, and neglecting terms of the second order, we obtain

$$\Delta E = \frac{\Delta x\sqrt{\gamma_1^2-\beta_1^2}}{\cos E_0''}.$$

Introducing now the value of Δx, and that of $\sqrt{\gamma_1^2-\beta_1^2} = 0{\cdot}01483$, we get [1]

$$\Delta E = \frac{0{\cdot}13 \times 0{\cdot}01483}{\cos E_0''}.$$

When E_0'' is 10°, ΔE is less than 7′; and when $E_0'' = 15°$ it is less than 9′.

Hence the effect on E of the change in $\dfrac{a}{\sqrt{\gamma^2-a^2}}$ is so small that it may be neglected, and it follows that P and Q of equation (1) may be replaced by their equivalents given in (3).

It is of interest to examine the change in the true optic axial angle, which is given by the equation:

$$\tan V = \frac{a}{\gamma}\sqrt{\frac{\gamma^2-\beta^2}{\beta^2-a^2}} \quad \left(\text{or, writing } z \text{ for } \frac{a}{\gamma\sqrt{\beta^2-a^2}}\right)$$

$$= z\sqrt{\gamma^2-\beta^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

[1] For $\lambda = 671\mu\mu$, $\gamma = 1{\cdot}52255$ and $\beta = 1{\cdot}52248$.

By computation, we find

for $\lambda = 486\mu\mu$, $z = 8{\cdot}349$,

and for $\lambda = 671\mu\mu$, $z + \Delta z = 8{\cdot}487$.

$$\therefore \quad \Delta z = 0{\cdot}138.$$

Now taking differences, we find from (4)

$$\Delta V = \Delta z \cos^2 V \sqrt{\gamma^2 - \beta^2}.$$

Now ΔV is greatest when $V = 0$, and $\lambda = 671\mu\mu$. Introducing the corresponding values, we find that

$$\Delta V < 0{\cdot}138 \times 0{\cdot}0148 < 8'.$$

Hence it follows that, within the stated range of the spectrum, the change in the factor $\frac{a}{\gamma\sqrt{\beta^2 - a^2}}$ produces no sensible effect in the angle V, and that the great dispersion of V results practically from the factor $\sqrt{\beta^2 - \gamma^2}$. The equation (4) may then be expressed by the dispersion formula:

$$\tan V = \sqrt{P_t + \frac{Q_t}{\lambda^2}}. \qquad \ldots\ldots \quad (5)$$

To test this transformation the values of V in specimen No. 1 were computed from β and the observed E, and are given in the second column of Table VIII. The coefficients P_t and Q_t were then computed in a manner similar to that by which P and Q of equation (1) were found. V' (given in column 3) was then determined by introducing into equation (5) their values, $P_t = 0{\cdot}0329$, and $Q_t = -7541{\cdot}2$.

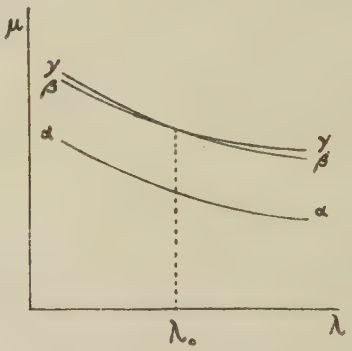
Table VIII.

λ in $\mu\mu$	V	V'	ΔV
478	0° 0′	—	—
478·9	—	0° 0′	—
486	1 54·3	1 47·0	+ 7·3′
508·5	3 22·2	3 29·7	− 7·5
535	4 30·25	4 37·6	− 7·35
589	5 58·7	6 1·8	− 3·1
644	6 59·7	6 55·0	+ 4·7
671	7 17·8	7 14·5	+ 3·3

These values are plotted in Plate X, fig. 2, on the same scale as the values of E. It is clear that the curves for both values agree very wel, and consequently equation (5) may also be employed to give the dispersion of the axial angle of the sanidine plate.

The Change in the Dispersion Formulae when E passes through Zero.

In the preceding discussion the plane of the optic axes was taken to be unchanged. When, however, E passes through zero, the plane changes through 90°, and β in the first axial plane becomes γ in s second position. In this new plane all that is needed to obtain the dispersion formulae for E and V is to change the signs of the coefficients P, Q and P_t, Q_t in equations (1) and (5).



Suppose the relative values of α, β, and γ for a crystal in which E passes through zero to be given by the curves in the accompanying text-figure, and λ_0 to be the wave-length for which $E = 0°$. At this point the plane of the optic axes turns through 90°, and the axis which was the mean principal axis becomes that of γ, whilst that corresponding to γ becomes the mean one. If now for values of $\lambda > \lambda_0$ the dispersion of the axial angle is represented by (1) and (5), then for values $\lambda < \lambda_0$ the dispersion is given by :—

$$\sin^2 E = -P - \frac{Q}{\lambda^2}, \quad \ldots\ldots\ldots \quad (1^*)$$

and

$$\tan^2 V = -P_t - \frac{Q_t}{\lambda^2}. \quad \ldots\ldots\ldots \quad (5^*)$$

To test this, the coefficients P and Q in equation (1*) were calculated from the observed values of E for different wave-lengths, the optic plane

being parallel to that of symmetry. These observations were made in one and the same part of specimen No. 2, care being taken to avoid using a different portion in which the optic angle varied. The values obtained were:

$$P_3 = -0{\cdot}048170$$
$$Q_3 = 16410{\cdot}4,$$

where the suffix 3 is used to denote the coefficients of curve (*e*).

Hence for curve (*e*) lying in the symmetry-plane the signs of P_3 and Q_3 are the reverse of those of P_1, Q_1, and P_2, Q_2, the coefficients respectively of the curves (*a*) and (*b*) which lie in planes perpendicular to that of symmetry.

Table IX gives the observed E and its values computed from the above constants P_3 and Q_3. In Plate X, fig. 2, the observed values in curve (*e*) are shown by large circlets, those computed from the dispersion formula (1*) by smaller circlets.

Table IX.

E of No. 2. *Axial Plane parallel to* (010).

λ in $\mu\mu$	Observed.	Calculated.	Difference.
486	8°28·3′	8°23·5′	+ 4·8′
508·5	7 4·0	7 6·3	− 2·3
535	5 26·3	5 29·5	− 3·2
554	4 4·8	4 10·5	− 5·7
575	—	2 11·7	—
584	—	0 0	—
585	0 0	—	—

It will be seen that the computed and observed values agree together very well, and so far justify the statement that in the second axial plane the signs of the coefficients are the reverse of those in the first.

There is some interest in seeing how the curves (*b*) and (*e*) would be continued in the plane at right angles to that in which the observations were actually made. The continuations obtained by changing the signs of P_2, Q_2 and P_3, Q_3 are shown in curves (*f*) and (*g*) of Plate X, fig. 2, and the computed values at the points indicated by circlets are given in Table X. There is a want of congruence at the point $E = 0°$ due to the divergence of the actual and computed points of uniaxiality already mentioned on p. 247.

Table X.

E in the Rotated Planes computed by changing the signs of the Coefficients of Curves (b) and (c).

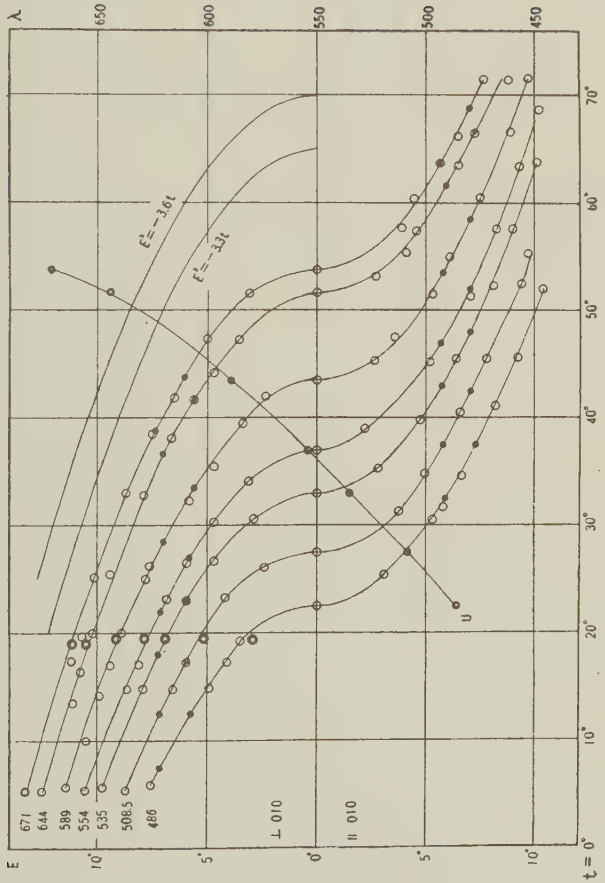
λ in μμ	Curve *f*	Curve *g*
	A. P. ∥ (010)	A. P. ⊥ (010)
486	7° 0·8′	—
508·5	5 17·3	—
535	2 32·2	—
544	0 0	—
583·6	—	0° 0′
589	—	1 41·2
610	—	3 39·3
644	—	5 19·2
671	—	6 12·8

Explanation of Plates.

Plate IX.—The abscissae give temperature, and ordinates on the left measured up and down from the zero-ordinate give the angle *E*. The simple circlets mark direct observations for the wave-lengths placed at one end of the curve on which they lie; the double circlets give direct observations without a heating cell. The black dots give the positions on each curve for temperatures differing from that of the zero-point by 10° and 15°. The parabolic curves above the zero-line give angles when the axial plane is perpendicular to that of symmetry, the lower parabolic portions give the angles when the axial and symmetry planes coincide. The parabolas without dots or circlets are the limiting ones described in the text (p. 242). The curve *U* gives the relation between temperature and wave-length at which the crystal becomes uniaxial—the wave-lengths in μμ on the ordinates shown by numbers on the right.

Plate X, fig. 1, gives the curves for equal temperatures, the abscissae measuring wave-lengths in μμ, and the ordinates the angle in air measuring from the zero-line, the curves above and below it being in the planes at right angles as indicated. The crosses give the points on the curves differing by equal differences of abscissae—25, 50, and 75 in μμ—from the zero-point.

Plate X, fig. 2, are *E* λ curves similar to those of fig. 1, except that the black dots and double circlets give the ordinates of *V*. The meaning of the circlets is given in the diagram.



S. Kôzu: Optic axial angle of Sanidine.

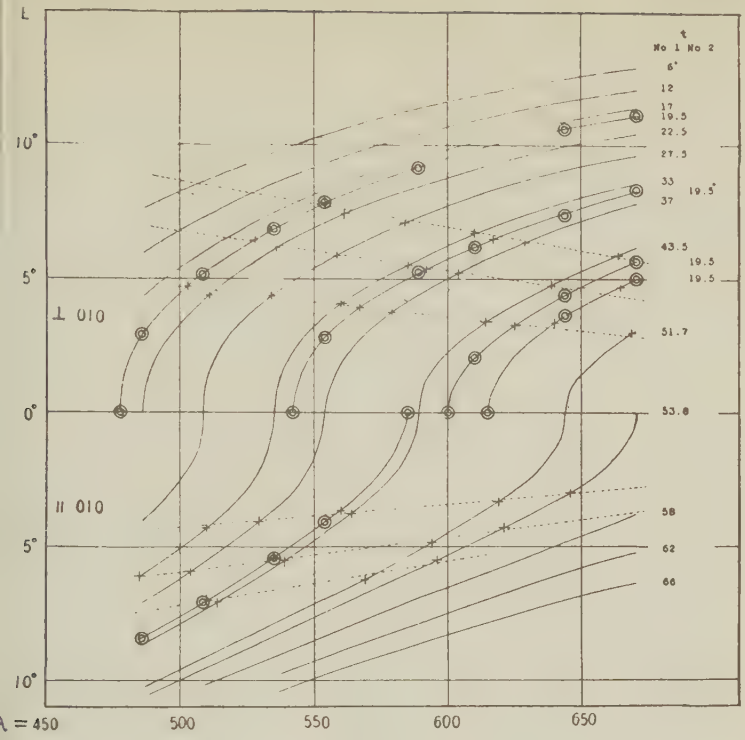

t
No 1 No 2
6°
12
17
19.5
22.5
27.5
33
37
19.5°
43.5
19.5
19.5
51.7
53.8
58
62
66
10°
5°
0°
5°
10°
⊥ 010
∥ 010
λ = 450
500
550
600
650

Fig. 1.

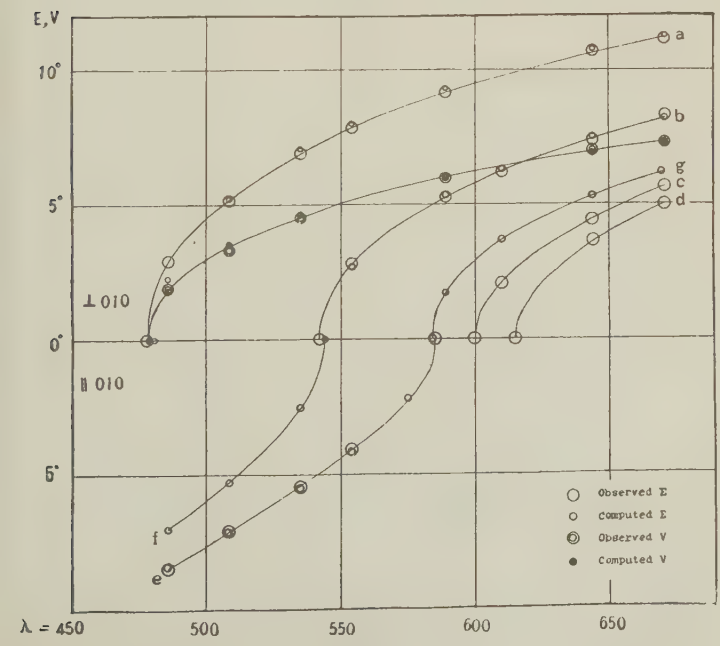

E,V
10°
5°
0°
5°
⊥ 010
∥ 010
a
b
g
c
d
f
e
Observed E
Computed E
Observed V
Computed V
λ = 450
500
550
600
650

Fig. 2.

The dispersion phenomena of some monoclinic Felspars.

By S. Kôzu,

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[Read March 16, 1915.]

1. Introduction.

In the present paper the dispersion of the refractive indices of monoclinic felspars from four different localities is given, likewise that of the optic axial angle and of the optic axes in some of them.

The method of investigation and instruments for these studies have been already mentioned in my previous paper.[1] As the refractive indices and dispersion of the glass hemisphere of the total-reflectometer have not so far been given, I shall in the first place state the way in which they have been determined and their values and the degree of accuracy attainable, for the dispersion of the glass hemisphere differs to an appreciable degree from that of other instruments of the same kind.

Refractive Indices and the Dispersion of the Glass Hemisphere.

Hilger's wave-length spectrometer was used to select from the Nernst lamp, or the arc-light, waves of the definite length. These were checked by employing the bright lines of lithium (671$\mu\mu$), sodium (589$\mu\mu$), thallium (535$\mu\mu$), given by a Bunsen burner, and the bright blue line of hydrogen obtained by sparking through a tube. The latter line was, however, read in the instrument as 485·2 instead of the correct number 486$\mu\mu$. The error from this cause has been neglected, and the light was taken to have the wave-length 486$\mu\mu$. As stated in this volume on p. 189, the dispersion of the hemisphere was compared with that of a glass prism, the dispersion of which was found by the method of minimum deviation. The goniometer used for the measurement

[1] S. Kôzu, 'The dispersion phenomena of albite from Alp Rischuna, Switzerland.' Mineralogical Magazine, 1915, vol. xvii, pp. 189–192.

of the angle and the minimum deviation of the glass prism was the large model made by the Fuess Company. The horizontal divided circle has a diameter of 25 cm. and is divided to 10 minutes. By means of the sliding micrometer placed in the eye-piece, readings to 10 seconds can be made.

The angle of the prism was measured in eight different positions of the goniometer-circle, three readings being taken in each position. The angles varied from 60° 0′ 10″ to 59° 59′ 30″; and the mean of the twenty-four readings is 59° 59′ 48″.

For the determinations of the dispersion of the prism, twelve different wave-lengths were used: 431, 455·5, 486, 508·5, 527, 535, 554, 589 (Na), 610, 644, 671, and 700 in $\mu\mu$ units as read in Hilger's spectrometer.

The minimum deviation of the prism for sodium-light was measured in four different positions of the circle; and in each case five readings were made on both sides of the fixed direction of the collimator. The results are given in Table I.

Table I.

Minimum Deviation of the Glass Prism for Sodium-light.

(Temperature 20° C., nearly.)

	Reading on right.	Reading on left.	Mean.
1	38°3′ 5″	38°2′ 20″	38°2′ 42″
2	38 3 10	38 2 40	38 2 55
3	38 2 45	38 3 3	38 2 54
4	38 2 33	38 3 17	38 2 55
Mean			38°2′51·5″

The refractive index of the prism for sodium-light is therefore 1·51000.

In determining the minimum deviations for the other wave-lengths only one position of the circle was used, five readings being made, as in the case of sodium-light, on both sides of the collimator. The observed minimum deviations δ and the corresponding refractive indices μ are given in Table II.

In order to increase the illumination in the above experiments a condenser was placed between the source of light and the spectrometer's collimator, for the opening of the slit was as narrow as possible. A second condenser was also placed in a suitable position between the spectrometer's telescope and the goniometer's collimator. This simple

Table II.

Minimum Deviations and Refractive Indices of the Glass Prism.

(Temperature 20° C., nearly.)

λ in μμ	δ	μ
431	38°58′18″	1·52057
455·5	38 46 26	1·51825
486	38 32 54	1·51572
508·5	38 24 54	1·51420
527	38 19 1	1·51308
535	38 16 13	1·51255
554	38 11 24	1·51163
589	38 2 51·5	1·51000
610	37 59 4	1·50928
664	37 52 46	1·50808
671	37 48 7	1·50719
700	37 43 50	1·50637

arrangement was very useful, for the first condenser increased the illumination, whilst the second enabled one to adjust any desired wave-length, since a distinct image of the pointer in the spectrometer's telescope could then be seen in that of the goniometer superposed on the bright line used.

Using the refractive indices thus obtained, those of the glass hemisphere of the total-reflectometer were measured, the precautions indicated by Viola[1] being carefully attended to. The results are given in Table III.

Table III.

Critical Angles and Refractive Indices of the Glass Hemisphere.

(Temperature 20° C., nearly.)

λ in μμ	θ	μ	Viola's determinations.
455·5	51°45′30″	1·9331	...
486	52 10 29	1·9190	1·91951
508·5	52 25 14	1·9106	...
527	52 35 29	1·9049	1·90572
535	52 39 26	1·9025	...
554	52 48 20	1·8976	...
589	53 1 30	1·8901	1·89040
610	53 8 41	1·8863	...
644	53 18 36	1·8807	...
671	53 24 48	1·8771	...
700	53 30 18	1·8738	...

[1] C. Viola, Zeits. Kryst. Min., 1900, vol. xxxii, pp. 311-314.

Of the wave-lengths employod by Viola only three agree with mine. Judging from the differences in these cases, the glass hemisphere of his instrument differed considerably from that used by me.

Gifford's[1] determination of the refractive indices of quartz by the minimum deviation method are extremely accurate, and they have been used by me to check my determinations of the indices of the hemisphere. For this purpose I used a quartz plate cut perpendicular to the optic axis, and the refractive indices obtained by the use of the hemisphere are given in column 3 of Table IV. I have only carried these values to the

Table IV.

Critical Angle θ and Principal Refractive Indices of Quartz and Fluorite.

(Temperature 20° C., nearly.)

λ in μμ	θ	ω and ε	Gifford.	Δ
	Quartz.[2]			
486	ω 53°51′52″	1·5498	1·54970	+0·00010
	ε 54 20 7	1·5591	1·55899	+0·00011
508·5	ω 54 7 34	1·5482	...	...
	ε 54 36 15	1·5575	...	...
527	ω 54 18 52	1·5472	1·54718	+0·00002
	ε 54 47 45	1·5565	1·55639	+0·00011
589 (Na)	ω 54 47 50	1·5444	1·54426	+0·00014
	ε 55 16 26	1·5535	1·55337	+0·00013
644	ω 55 5 45	1·5424	1·54231	+0·00009
	ε 55 35 7	1·5515	1·55135	+0·00015
671	ω 55 12 26	1·5415	1·54146	+0·00004
	ε 55 41 26	1·5504	1·55047	−0·00007
	Fluorite.			
486	48°29′ 5″	1·4369	1·43707	−0·00017
527	48 54 7	1·4355	1·43556	−0·00006
589	49 20 37	1·4339	1·43385	+0·00005
671	49 44 51	1·4326	1·43226	+0·00034

[1] J. W. Gifford, Proc. Roy. Soc., London, 1902, vol. lxx, p. 329; 1910, ser. A, vol. lxxxiv, p. 193.

[2] The refractive indices of quartz for different wave-lengths, determined by Mülheims and Viola by the method of total reflection, are given in Zeits. Kryst. Min., 1888, vol. xiv, p. 224, and 1900, vol. xxxii, p. 314, respectively. For comparison, the indices determined by them for three wave-lengths employed by me are cited below:—

	486μμ (F)		527μμ (E)		589μμ (D)	
	ω	ε	ω	ε	ω	ε
Mülheims	1·54965	1·55896	1·54708	1·55639	1·54423	1·55328
Viola	1·54992	1·55910	1·54751	1·55657	1·54435	1·55342

fourth place of decimals, for a greater degree of accuracy is not to be expected from the method. Gifford gives the indices to six places of decimals, but in column 4 I have given only five, the fifth figure being increased by unity if his sixth exceed 5. The differences between his and my values are given in column 5. As a further check the refractive indices of a fluorite plate determined by me are compared with those given by Gifford for this mineral.

Owing to several circumstances the same order of accuracy cannot in general be attained with the felspars, for the transparency of the crystals, the size and perfection of the polished plane surface, and the intensity of the light all affect the distinctness of the shadows. The felspars examined were :—

Adularia from St. Gotthard, Switzerland (Cambridge Museum).

Adularia from Riedertobel, Bristenstock, Switzerland (Cambridge Museum).

Moonstone from Ceylon (Cambridge Museum).

Orthoclase from Madagascar.

2. Adularia from St. Gotthard, Switzerland.

(Tables V–VIII.)

The crystal is a triple twin according to the Baveno-law, and forms a rectangular prism bounded by three rough faces (001), and a dull double face (010). The most conspicuous terminal faces are x ($\bar{1}01$). The basal plane is traversed by numerous crevices parallel to the edge (001, $\bar{1}01$). The material is, as far as examination under the microscope enables one to judge, pure, transparent, and almost free from inclusions. The extinction-angle on (010) makes 5° with the edge (010, 001) in the obtuse angle $X \wedge Z$.

Dispersion of the Principal Indices.

The plate prepared for this determination was tested in white light in the polarizing microscope, and found to be practically perpendicular to the acute bisectrix.[1] The crystal is negative, and the optic axial planes for all colours are perpendicular to that of symmetry. Hence the obtuse bisectrix (Bx_o) coincides with the dyad axis of the crystal, which is a fixed direction. It is therefore only necessary to find this direction, or

[1] It is clear that the plate need not be perpendicular to the acute bisectrix, as long as it is at right angles to the plane of symmetry of the crystal. When the plane of observation is perpendicular to that of symmetry, two principal indices for each λ are determined with accuracy; and when the two planes coincide, the third index is accurate, but not necessarily the other.

that of the symmetry-plane, in the plate to be able to determine α, β, and γ. For (1) when the plane of observation is perpendicular to that of symmetry β and α are found, and (2) when the two planes coincide γ and α_1 are found. The first three values are correct, for the shadows are due to vibrations parallel to principal axes. The last, α_1, is due to vibrations perpendicular to the plate, and is not for all colours a principal index. Hence it is not strictly accurate, though the error in a case such as this is so small as to be negligible. Position (2) of the plate was fixed and noted when the latter had been shifted so as to give the critical angle θ_γ for sodium-light; and in a like manner position (1) was fixed by the determination of θ_β for the same colour. The positions so fixed served for the measurement of the critical angles for other colours. The critical angles observed for a number of wave-lengths, and their variations from those for sodium-light, are given in Table V; the refractive indices corresponding to the critical angles and the birefringencies in Table VI.

Table V.

Observed Critical Angles.

(Temperature 19° C., nearly.)

λ in $\mu\mu$	θ_α	$\Delta\theta_\alpha$	θ_β	$\Delta\theta_\beta$	θ_γ	$\Delta\theta_\gamma$
486	52°34·39′	−52·98′	52°46·86′	−52·55′	52°51·32′	−52·49′
508·5	52 49·47	−37·90	53 1·86	−37·55	53 6·52	−37·29
535	53 5·16	−22·21	53 16·56	−22·85	53 21·32	−22·49
554	53 13·89	−13·48	53 25·26	−14·15	53 30·07	−13·34
589 (Na)	53 27·37	0 0	53 39·41	0 0	53 43·81	0 0
610	53 34·84	+ 7·37	53 46·66	+ 7·25	53 51·29	+ 7·48
644	53 43·44	+16·07	53 56·31	+16·90	54 0·55	+16·74
671	53 51·02	+23·65	54 2·81	+23·40	54 7·00	+23·19

Table VI.

Refractive Indices and Birefringencies.

λ in $\mu\mu$	α	β	γ	$\gamma-\alpha$	$\gamma-\beta$	$\beta-\alpha$
486	1·5239	1·5282	1·5297	0·0058	0·0015	0·0043
508·5	1·5224	1·5264	1·5281	0·0057	0·0017	0·0040
535	1·5211	1·5249	1·5265	0·0054	0·0016	0·0038
554	1·5201	1·5239	1·5255	0·0054	0·0016	0·0038
589 (Na)	1·5185	1·5225	1·5239	0·0054	0·0014	0·0040
610	1·5178	1·5217	1·5232	0·0054	0·0015	0·0039
644	1·5162	1·5203	1·5217	0·0055	0·0014	0·0041
671	1·5154	1·5195	1·5208	0·0054	0·0013	0·0041

Dispersion of the Optic Angle, Optic Axes, and Optic Axial Plane.

The dispersion of the axial angle was measured by the Hutchinson universal goniometer, the plate being immersed in a liquid of known refractive index for each wave-length. The observed value $2H$, the deduced value $2V$, and the corresponding refractive indices—μ of the liquid and β of the plate—are given in Table VII.

The dispersion of the optic axes for each wave-length was determined by measurements made along two directions—one along the optic axial plane and the other perpendicular to it, the measurements in both cases being made with reference to the position of the axes for sodium-light. The former angular distance (which for the present purpose may be termed horizontal angular distance of the optic axes) was directly measureable by the horizontal circle of the goniometer, for it is merely the difference of H for different colours; and the second angular distance (vertical angular distance, say) was obtained by a cross-hatched eye-piece, one

Table VII.

Dispersions of the Optic Axial Angles.

(Temperature 18·5° C.)

λ in $\mu\mu$	$2H$	V	μ (of liquid)	β
486	59° 57·2′	60° 45·7′	1·5468	1·5282
508·5	60 12·5	60 55·6	1·5419	1·5264
535	60 30·5	61 8·3	1·5393	1·5249
589	61 1·4	61 30·4	1·5333	1·5225
644	61 27·5	61 50·9	1·5290	1·5203
671	61 39·5	61 59·2	1·5275	1·5195

division of which corresponds to 16′ of arc. The results obtained are given in Table VIII (p. 260).

In this table the figures given in columns A and B are the horizontal angular distances of the two optic axes, measured separately from the corresponding axes for sodium-light taken as zero points. The signs + and − denote increment and decrement of the angles, respectively. The values of A and B do not agree very well; and the differences must be due to experimental errors, the principal source of which is the lack of distinctness of the isogyres. One isogyre, to which A refers, was

Table VIII.

Dispersion of the Optic Axes.

λ in μμ	Horizontal angular distance.					Vertical angular distance.	
	A	*B*	Mean of *A* and *B*	Δ*V*	*H*	Δ*I*	Δ*U*
486	−33·3′	−30·5′	−31·9′	−22·3′	−34·35′	−32·0′	−20·9′
508·5	−29·5	−22·0	−25·8	−17·4	−29·45	−24·0	−15·7
535	−16·5	−14·0	−15·3	−11·0	−15·25	−16·0	−10·5
589	0	0	0	0	0	0	0
644	+15·0	+11·0	+13·0	+10·3	+13·05	+12·8	+ 8·5
671	+19·0	+16·0	+17·5	+14·4	+19·05	+16·0	+10·5

better defined than the other, and therefore the values of *A* may be taken as the more accurate. In column 6, Δ*H* for each wave-length is computed from the data (Δ*V*, β, and μ) of Table VII by the formula $\Delta H = \frac{\beta}{\mu}\Delta V$. It will be seen that these figures agree well with those given in column *A*, which were the values derived from the distinct isogyre.

The observed vertical angular distances, Δ*I* (say), of the optic axes for the same wave-lengths are given in column 7, and the corresponding value, Δ*U*, in the crystal given in column 8, has been found by the equation $\Delta U = \frac{\Delta I}{\beta}$. The sign attached to Δ*I* indicates an increase or decrease in the angle made by the optic axial plane with (001).

3. Adularia from Riedertobel, Bristenstock, Switzerland.

(Tables IX and X.)

The crystal used was a simple one bounded by the prism (110) and by ($\bar{1}$01) and (001); the habit was as shown in fig. 7 of Dana's 'System of Mineralogy.' 1892 (p. 316). The section, which was cut nearly parallel to (100), was transparent and colourless. The examination was made with light of five different wave-lengths only. The observed critical angles, and the corresponding refractive indices and birefringencies are given in Tables IX and X, respectively.

Table IX.

Observed Critical Angles.

(Temperature 19·4° C.)

λ in μμ	θ_α	$\Delta\theta_\alpha$	θ_β	$\Delta\theta_\beta$	θ_γ	$\Delta\theta_\gamma$
508·5	52°54·19′	−37·66′	53° 5·93′	−37·72′	53° 9·31′	−37·49′
535	53 9·37	−22·48	53 20·44	−23·21	53 24·00	−22·80
589	53 31·85	0	53 43·65	0	53 46·80	0
644	53 48·31	+16·46	54 0·12	+16·47	54 3·81	+17·01
671	53 55·31	+23·46	54 7·43	+23·78	54 10·87	+24·07

Table X.

Refractive Indices and Birefringencies.

λ in μμ	α	β	γ	$\gamma-\alpha$	$\gamma-\beta$	$\beta-\alpha$
508·5	1·5240	1·5279	1·5290	0·0050	0·0011	0·0039
535	1·5226	1·5262	1·5274	0·0048	0·0012	0·0036
589	1·5200	1·5238	1·5249	0·0049	0·0011	0·0038
644	1·5177	1·5215	1·5227	0·0050	0·0012	0·0038
671	1·5171	1·5209	1·5220	0·0049	0·0011	0·0038

It will be noticed that these refractive indices are all higher than the corresponding ones of the St. Gotthard specimen—about 0·0015 for α, about 0·0013 for β, and about 0·0010 for γ.

4. Moonstone from Ceylon.

(Tables XI–XIII.)

This mineral has been regarded by mineralogists as a variety of adularia showing schillerization. The specimen studied in the Cambridge Museum differs remarkably in its optical properties from the preceding specimens of adularia. This difference[1] may be a consequence of the

[1] A chemical analysis of the Ceylon moonstone, recently made by E. H. Kraus (Zeits. Kryst. Min., 1901, vol. xxxiv, p. 175), is as follows :—

	SiO_2.	Al_2O_3.	CaO.	K_2O.	Na_2O.	Loss of Ignition.	Total.
%	65·87	19·45	0·51	11·91	2·57	0·18	100·49
Mol. prop.	1·098	0·190	0·009	0·127	0·042		

From this analysis, the molecular formula computed by me is given as

$$Or_{73\cdot2}Ab_{24\cdot2}An_{2\cdot6}.$$

presence of much soda, for it is well known that the refractive indices increase with the soda. The samples used were fragments bounded by the perfect basal cleavage and the less perfect one parallel to the side pinakoid (010), and in some cases by prismatic faces, which were identified as (110) and (100). The angles between the cleavage planes parallel to (001) and (010) were measured on three pieces by the reflection goniometer. They were 89° 58′, 90° 1′, and 90° 2′, and thus it appears that this crystal can be taken as belonging to the monoclinic system. The material is sometimes discoloured (of a pale brown colour) along the cleavage or parting face, but otherwise it is fresh. Its characteristic schillerization can be distinctly seen on the two different parting faces—one near the front pinakoid (100), and the other almost parallel to (110). The parting planes are generally uneven and curved, but are sometimes fairly even. According to Des Cloizeaux, the plane of maximum schillerization is nearly coincident with (100) and is inclined to the base at angles varying from 65° to 69°; but I have found the angle to be much more variable, and on the three fragments measured the angles were 62°, 70°, and 75°. The other schillerization-plane makes with the basal cleavage angles varying between 80° and 86°—the angles measured on five fragments were 80½°, 81°, 82½°, 84°, and 86°. The transparency varies according to the direction in which light passes through the crystal. Fairly thick sections parallel to the base and the side pinakoid are transparent. For instance, an incandescent gas-light was in a dark room seen through a plate, 6 mm. thick, cut and polished parallel to the base; but no distinct image of the light could be seen through a similar plate, 2 mm. thick, when the polished surfaces were parallel to the maximum schillerization-face.

Dispersion of the Refractive Indices and the Axial Angle.

The section employed for these determinations was practically perpendicular to (010), and made an angle of 68° 59′ with (001). It was inclined at nearly 16° to the acute bisectrix, but since the section is perpendicular to the symmetry-plane, the critical angles for the different principal indices are not affected by the inclination of the bisectrix to the plane of section. The method of observation is the same as that already described.

Three observations, given below, of each of the critical angles for sodium-light were made, and the arithmetical mean was employed to give the indices.

	θ_α	α	θ_β	β	θ_γ	γ
1	53°40·20′	1·5227	53°53·50′	1·5271	53°59·30′	1·5289
2	53 39·92	1·5226	53 53·13	1·5269	53 59·20	1·5289
3	53 39·82	1·5226	53 53·55	1·5271	53 59·27	1·5289
Mean	53 39·98	1·5226	53 53·39	1·5270	53 59·27	1·5289

The axial angle computed from the principal refractive indices is $2V = 66° 19·7′$, and the observed value, given in Table XIII, is 66° 24′—an agreement so close that it can only be regarded as accidental (see page 273).

Table XI.

Observed Critical Angles.

(Temperature 19° C., nearly.)

λ in μμ	θ_α		θ_β		θ_γ	
	I	II	I	II	I	II
486	52°47·62′	52°47·39′	53° 1·06′	53° 0·75′	53° 6·67′	53° 6·39′
508·5	53 2·63	53 1·86	53 16·38	53 16·28	53 21·56	53 21·85
535	53 17·13	53 16·86	53 30·55	53 30·55	53 36·81	53 36·92
554	—	53 25·93	—	53 39·65	—	53 45·54
589 (Na)	53 40·20	53 39·82	53 53·50	53 53·55	53 59·30	53 59·27
610	—	53 47·04	—	54 0·85	—	54 6·47
644	53 57·25	53 56·36	54 10·81	54 10·17	54 17·14	54 16·52
671	54 4·08	54 3·14	54 17·06	54 17·11	54 23·31	54 23·24

Table XII.

Refractive Indices and Birefringencies.

λ in μμ	α	β	γ	$\gamma-\alpha$	$\gamma-\beta$	$\beta-\alpha$
486	1·5283	1·5328	1·5347	0·0064	0·0019	0·0045
508·5	1·5265	1·5313	1·5332	0·0067	0·0019	0·0048
535	1·5250	1·5296	1·5316	0·0066	0·0020	0·0046
554	1·5241	1·5286	1·5305	0·0064	0·0019	0·0045
589 (Na)	1·5226	1·5270	1·5289	0·0063	0·0018	0·0045
610	1·5218	1·5263	1·5281	0·0063	0·0018	0·0045
644	1·5203	1·5248	1·5268	0·0065	0·0020	0·0045
671	1·5196	1·5240	1·5260	0·0064	0·0020	0·0044

The critical angles—θ_α, θ_β, and θ_γ—for other wave-lengths were with few exceptions measured on two different occasions and are given in columns I and II of Table XI (p. 263). The table shows that the results obtained at different times agree very well, for the greatest differences (θ for 644 and 671 $\mu\mu$) do not exceed one minute, which corresponds to about 3 units in the fourth decimal place of the corresponding refractive index.

The refractive indices given in Table XII (p. 263) were computed from the mean values of I and II in Table XI, with the exception of those for sodium-light, in which three observations were taken owing to the greater precision attainable with this colour.

Table XIII gives the axial angles for different wave-lengths, the notation used being the same as before. As already stated, the plate was not perpendicular to the acute bisectrix, and to avoid error arising from this cause a liquid was used with a refractive index equal to β_{Na} of the crystal. Hence the angle $2H$ is correct for sodium-light, but not so for other colours. The error, however, arising from the difference of dispersion of the liquid and the index β is in all cases small.

Table XIII.

Dispersion of the Axial Angles.

(Temperature 18° C., nearly.)

λ in μ	$2H$	$2V$	μ (liquid)	β
486	65° 14·5′	65° 29·5′	1·5380	1·5328
508·5	65 34·0	65 43·6	1·5346	1·5313
535	65 51·0	65 56·9	1·5316	1·5296
589	66 24·0	66 24·0	1·5271	1·5271
644	66 48·8	66 44·1	1·5232	1·5248
671	66 56·5	66 50·0	1·5219	1·5240

5. Orthoclase from Madagascar.

(Tables XIV to XVII.)

The crystals examined by me were bought in London, and the locality is given as Fianarantsoa, Madagascar. They are transparent and of pale yellow colour, with rather depolished faces. According to Prof. A. Lacroix,[1] yellow crystals of felspar are found in the gneissic region of

[1] A. Lacroix, Compt. Rend. Acad. Sci. Paris, 1912, vol. clv, p. 672; Minéralogie de la France, 1913, vol. v, pp. 28–29.

Itrongahy, between Betroka and Benenitra, south of Fianarantsoa, and occur scattered in the soil, or embedded in calcareous tufa, together with large transparent crystals of diopside, apatite, and quartz. In his opinion these minerals have been derived from a pegmatite with miarolitic structure. He says: 'Ce feldspath est souvent jaune et parfois même d'un jaune d'or foncé qui ne disparaît pas à la suite d'un chauffage prolongé au rouge . . . Les variations de densité (2·558 à 2·597) . . .'

Some of my specimens showed crystallographic faces which are more or less corroded and depolished, suggesting that the mineral has suffered erosion: but the interior seemed quite unaltered, and no want of transparency was observed, nor any change in the optic character of different parts of the plate. Most of the crystals were tabular with the side pinakoid (010) largely developed, one was prismatic and elongated along the vertical axis, another also prismatic but elongated along the X axis. The faces observed on different specimens are: c (001), b (010), m (110), z (130), y ($\bar{2}01$), x ($\bar{1}01$), a (100), and n (021).

Through the courtesy of Mr. A. Hutchinson, the specific gravity of the specimen examined optically was determined by four students in the Cambridge Mineralogical Laboratory by the suspension method. The mean of their results is $2{\cdot}564 \pm 0{\cdot}002$.

Dispersion of the Principal Indices.

The plate was cut practically perpendicular to the acute bisectrix, the optic axial plane being parallel to (010). The critical angles for sodium-light were measured on two occasions in the way already described, and the mean values were adopted. They gave the principal indices:[1] $\alpha = 1{\cdot}5216$, $\beta = 1{\cdot}5259$, and $\gamma = 1{\cdot}5261$. Computing the axial angle from these indices by the tangent formula, we obtain $2V = 24° 12{\cdot}8'$. This value is greater by $3° 55{\cdot}7'$ than that computed from β and $2E$, the angle measured with the universal goniometer (see Table XVI).

When the value of $\gamma - \beta$ differs very little from zero, very small variations in γ and β, lying within the limits of error in the observations, give rise to great differences in $2V$. Thus, for example, leaving α and γ unchanged, but taking β to be 1·5260 (a difference in the fourth decimal place of one unit, which corresponds to $23''$, or $0{\cdot}4'$, in the critical angle θ_β) we find $2V$ to be $17° 18'$. It is obvious that in such a case

[1] The indices given by Lacroix are $\alpha = 1{\cdot}5197$, $\beta = 1{\cdot}5248$, and $\gamma = 1{\cdot}5253$; the specimen having the density 2·565.

the true axial angle is hardly obtainable by computation from its refractive indices determined by the total-reflectometer.

As before, the critical angles for other wave-lengths were measured along the directions corresponding to the principal indices for sodium-light; these values are given in Table XIV and the corresponding refractive indices and birefringencies in Table XV.

Table XIV.

Observed Critical Angles.

(Temperature 19° C., nearly.)

λ in $\mu\mu$	θ_α	$\Delta\theta_\alpha$	θ_β	$\Delta\theta_\beta$	θ_γ	$\Delta\theta_\gamma$
486	52°44·0′	−52·9′	52°57·7′	−52·3′	52°58·8′	−51·7′
508·5	52 59·3	−37·6	53 12·9	−37·1	53 13·6	−36·9
535	53 14·1	−22·8	53 27·3	−22·7	53 28·3	−22·2
589	53 36·9	0	53 50·0	0	53 50·5	0
644	53 53·3	+16·4	54 7·1	+17·1	54 7·6	+17·1
671	53 59·1	+22·2	54 14·0	+24·0	54 14·5	+24·0

Table XV.

Refractive Indices and Birefringencies.

λ in $\mu\mu$	α	β	γ	$\gamma-\alpha$	$\gamma-\beta$	$\beta-\alpha$
486	1·5272	1·5318	1·5322	0·0050	0·0004	0·0046
508·5	1·5257	1·5302	1·5305	0·0048	0·0003	0·0045
535	1·5241	1·5285	1·5288	0·0047	0·0003	0·0044
589	1·5216	1·5259	1·5261	0·0045	0·0002	0·0043
644	1·5193	1·5238	1·5240	0·0047	0·0002	0·0045
671	1·5184	1·5230	1·5232	0·0048	0·0002	0·0046

The Dispersion of the Axial Angle and of the Optic Axes.

The axial angles for different wave-lengths are given in Table XVI, the angle $2E$ being measured in air. The columns 3 and 4, containing $2V$, show clearly the differences in the angles given by the two methods. The angles $2E$ are the arithmetical mean of four readings for each wave-length, the temperature of the room varying between 19·8° and 20·3° C.

The trend of the dispersion curve of the angle E is noteworthy, for if the curve is drawn on millimeter paper, in the same way as those of the Eifel sanidine given in Plate X, fig. 1, it is found to be concave down-

wards, whilst those of the sanidine when the axial plane coincided, as in this crystal, with that of symmetry were concave upwards. Therefore, if we suppose that at 20° C. the axial angle of the Madagascar sanidine vanishes for a greater wave-length, there must be two inflection points on the curve. This is extremely improbable, and we conclude that E must have a minimum value which may occur for a definite or infinite wave-length. One of the Eifel sanidines in the Cambridge Museum has its axial plane coincident with that of symmetry, and the dispersion curve of E shows a like trend, but the minimum angle, like that of the

Table XVI.

Dispersion of the Optic Axial Angles.

	Madagascar orthoclase (t = 19·8°—20·3° C.)				Eifel sanidine (t = 19° C.)
λ in $\mu\mu$	$2E$	$2V$ computed from E and β.	$2V$ computed from the refractive indices.	β	$2E$ (see p. 268).
486	38° 53′	25° 9·5′	32° 44·7′	1·5318	33° 16·0′
508·5	36 54·6	23 42·7	28 56·0	1·5302	31 54·0
535	34 46·0	22 32·7	29 7·5	1·5285	30 34·0
589	31 10·5	20 17·1	24 12·8	1·5259	28 4·6
644	28 7·5	18 21·0	23 15·2	1·5238	25 58·0
671	26 43·5	16 27·7	22 46·2	1·5230	24 53·0

Table XVII.

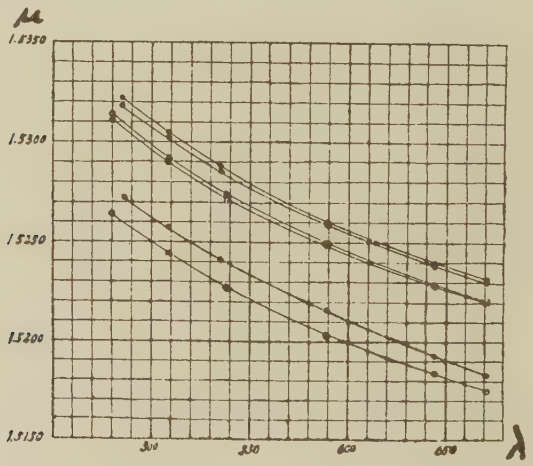
Dispersion of the Optic Axes and of the Acute Bisectrix Bx_a.

(Temperature 17·5°—18·4° C.)

in $\mu\mu$	ΔH observed.		ΔV computed from $\frac{\mu}{\beta}\Delta H$.		Dispersion of Bx_a.	Refractive index of liquid (μ).
	A	*B*	*A*	*B*		
486	+2° 5·0′	+2° 46·7′	+2° 7·3′	+2° 49·2′	−21·0′ (?)	1·5359
508·5	+1 27·5	+2 9·7	+1 29·1	+2 11·2	−21·0	1·5326
535	+0 55·75	+1 23·2	+0 56·6	+1 23·9	−13·7	1·5297
589	0 0	0 0	0 0	0 0	0	1·5252
644	−0 45·0	−1 2·8	−0 45·6	−1 3·5	+ 9·0	1·5216
671	−1 2·25	−1 30·0	−1 3·0	−1 30·7	+13·9	1·5202

Madagascar specimen, does not fall within the limits of the wave-lengths employed. The data are set out in Table XVI (p. 267).

Since the position of the optic axes in the symmetry-plane is not fixed by any line of symmetry, it is convenient to refer their dispersions, ΔH, to the position of the two axes A and B for sodium-light; the axis B being that lying in the acute angle between Bx_a and the vertical axis Z. The observed values ΔH are given under the headings A and B in columns 2 and 3 of Table XVII (p. 2 7). The corresponding values of ΔV of columns 4 and 5 are computed by the formula $\Delta V = \frac{\mu}{\beta} \Delta H$. The dispersion of Bx_a, referred to the position of that for sodium-light, is clearly one-half the difference between A and B of columns 4 and 5, and is taken as negative when the bisectrix moves towards B, and positive when it moves towards A.



The Dockweiler sanidine examined by Offret[1] shows relations similar to those of the Madagascar specimen, for in both the birefringence $\gamma - \beta$ is extremely small and increases as λ diminishes. Consequently the optic axial angle increases rapidly as λ diminishes. Though his refractive indices, determined at 22° C., are considerably lower than those of the Madagascar specimen measured at 20° C., the dispersion curves of the refractive indices shown in the accompanying text-figure are extremely similar. The black dots give the actual values found for the Madagascar

[1] A. Offret, Bull. Soc. franç. Min., 1890, vol. xiii, p. 645.

felspar. The circlets on the corresponding Dockweiler curves give the values in Offret's tables for the wave-lengths used by him.

From what has been stated above, the Madagascar felspar is to be compared with the sanidine group by reason of its small optic axial angle and very low birefringence ($\gamma - \beta$), but its refractive indices are much higher than those of the other members of the group.

6. Criticism of the Dispersion Formulae.

The dispersion formulae of the axial angle :—

$$\sin E = \sqrt{P + \frac{Q}{\lambda^2}}, \quad \ldots \ldots \quad (1)$$

and

$$\tan V = \sqrt{P_t + \frac{Q_t}{\lambda^2}}, \quad \ldots \ldots \quad (2)$$

which have been proved to be applicable to the Eifel sanidine, were tested for that from Madagascar, and also for the St. Gotthard adularia and the Ceylon moonstone. For the first of these both equations were examined, but for the two others only the tangent formula was applied, as their axial angles were not directly observed in air.

The Madagascar Orthoclase.

The two sets of coefficients—P, Q and P_t, Q_t—in equations (1) and (2) were computed, in a way similar to that described in the paper on the Eifel sanidine (p. 246), from the observed E, and from the V which was computed from E and β. The results are :—

$$P = -0{\cdot}00981, \qquad Q = 28460{\cdot}6.$$
$$P_t = -0{\cdot}00506, \qquad Q_t = 12886{\cdot}5.$$

Table XVIII gives the observed E, and the E' computed by introducing the values of P and Q in equation (1); and also the values of V computed from E and β, and those of V' deduced from equation (2) by the introduction of the values of P_t and Q_t.

The table shows that the differences ΔE and ΔV are very small. Hence it follows that equations (1) and (2) may be accepted as giving the dispersion formulae of E and V for this crystal.

Similarly as before, the variations of

$$x = \frac{a}{\sqrt{\gamma^2 - a^2}}, \text{ and of } z = \frac{a}{\gamma\sqrt{\beta^2 - a^2}},$$

Table XVIII.

λ in μμ	E observed in air.	E' computed from formula (1).	ΔE	V computed from E and β.	V' computed from formula (2).	V
486	19°26·5′	19°26·0′	+0·5′	12°34·8′	12°32·5′	+2·3′
508·5	18 27·3	18 27·5	−0·2	11 56·3	11 56·9	−0·6
535	17 23·0	17 25·2	−2·2	11 16·3	11 18·3	−2·0
589	15 35·2	15 35·5	−0·3	10 8·5	10 9·3	−0·8
644	14 3·7	14 1·5	+2·2	9 10·5	9 9·7	+0·8
671	13 22·0	13 21·7	+0·3	8 43·9	8 43·7	+0·2

within the given range of wave-lengths were determined, and they were found to be negligible in the computation of E and V, for the former is 0·0068, and the latter 0·0701.

Using the observed β, we get $\sqrt{\gamma^2-\beta^2} = 0{\cdot}0329$; and using β deduced from observed E, γ, and α, $\sqrt{\gamma^2-\beta^2} = 0{\cdot}0268$.

Therefore in the first case:—

$$\Delta E_{'} = \frac{0{\cdot}0068 \times 0{\cdot}0329}{\cos E_0},$$

and in the second case:—

$$\Delta E_{''} = \frac{0{\cdot}0068 \times 0{\cdot}0268}{\cos E_0}.$$

When E_0 is 20°, $\Delta E_{'}$ and $\Delta E_{''}$ are both less than 1′.

Again, $$\Delta V_{'} = 0{\cdot}0701 \times 0{\cdot}0329 \times \cos^2 V_0,$$

and $$\Delta V_{''} = 0{\cdot}0701 \times 0{\cdot}0268 \times \cos^2 V_0.$$

When $V_0 = 8°$, the larger of these is less than 9′, and the smaller is less than 7′.

The St. Gotthard Adularia and the Ceylon Moonstone.

The values of P_t and Q_t computed as before are:—

$P_t = 0{\cdot}38024$, $Q_t = -\ 8859{\cdot}0$ for adularia.

and $P'_t = 0{\cdot}46005$, $Q'_t = -11054{\cdot}5$ for moonstone.

In Table XIX, the angles V and V_1 computed from H, μ, and β (see Tables VII and XIII) are given in columns 2 and 5, and in columns 3 and 6 are those, V' and V_1', obtained by introducing the above values

Table XIX.

λ in μμ	Adularia, St. Gotthard.			Moonstone, Ceylon.		
	V computed from H, μ, and γ (see Table VII).	V' computed from formula (2).	ΔV	V_1 computed from H, μ, and β (see Table XIII).	V_1' computed from formula (2).	ΔV_1
486	30°22·9′	30°20·9′	+2·0′	32°44·8′	32°44·1′	+0·7′
508·5	30 27·8	30 27·9	−0·1	32 51·8	32 51·7	+0·1
535	30 34·2	30 35·0	−0·8	32 58·5	32 59·3	−0·8
589	30 45·2	30 46·4	−1·2	33 12·0	33 12·0	+0·0
644	30 55·5	30 55·5	0·0	33 22·1	33 21·5	+0·6
671	30 59·6	30 59·0	+0·6	33 25·0	33 25·4	−0·4

of P_t, P_t' and Q_t, Q_t' in equation (2). The differences ΔV and ΔV_1 between them are very small, and are practically negligible.

The changes of $z = \dfrac{a}{\gamma\sqrt{\beta^2-a^2}}$ for both adularia and moonstone, and their effects on V were also tested.

The results are:—

for adularia, $\Delta V = \Delta z\sqrt{\gamma^2-\beta^2}\,.\,\cos^2 V = 0{\cdot}1372 \times 0{\cdot}06403 \times \cos^2 V$,

if $V = 30°$, $\Delta V = 22{\cdot}6'$;

for moonstone, $\Delta V = 0{\cdot}02754 \times 0{\cdot}24535 \times \cos^2 V$,

if $V = 33°$, $\Delta V = 16{\cdot}3'$.

These results are unsatisfactory; but, as shown later on, small errors in the refractive indices cause appreciable changes in the axial angle, and also in Δz. For example, suppose that in the calculation of Δz and ΔV for adularia, the a for 486 μμ to be *alone* changed, and this by 0·0001. Making then $a = 1{\cdot}5240$ instead of 1·5239, Δz becomes 0·0549 instead of 0·1372, and ΔV becomes $= 9{\cdot}3'$. It follows therefore that, when $\sqrt{\gamma^2-\beta^2}$ is not very small, there will be considerable uncertainty as to the effect of the variation of $z = \dfrac{a}{\gamma\sqrt{\beta^2-a^2}}$, as long as the indices are liable to errors in the fourth decimal place.

7. The effect on $2V$ of errors in the Refractive Indices.

The effect on $2V$ (measured about the axis of least elasticity) of errors in α, β, and γ are given by differentiation of the formula :—

$$\tan V = \frac{\gamma\sqrt{\beta^2-\alpha^2}}{\alpha\sqrt{\gamma^2-\beta^2}}.$$

The difference dV is given by :—

$$dV = \frac{\partial V}{\partial \alpha}d\alpha + \frac{\partial V}{\partial \beta}d\beta + \frac{\partial V}{\partial \gamma}d\gamma,$$

where

$$\frac{\partial V}{\partial \alpha} = -\frac{\gamma\sqrt{\gamma^2-\beta^2}}{(\gamma^2-\alpha^2)\sqrt{\beta^2-\alpha^2}},$$

$$\frac{\partial V}{\partial \beta} = \frac{\alpha\gamma}{\beta\sqrt{(\beta^2-\alpha^2)(\gamma^2-\beta^2)}},$$

and

$$\frac{\partial V}{\partial \gamma} = -\frac{\alpha\sqrt{\beta^2-\alpha^2}}{(\gamma^2-\alpha^2)\sqrt{\gamma^2-\beta^2}}.$$

ΔV_1 about the other bisectrix can only differ from ΔV in sign, and consequently the partial differentials must also change sign.

The errors to which the refractive indices, determined by the Abbé-Pulfrich total-reflectometer, are liable lie, with few exceptions, within the limits of $\pm 0{\cdot}0002$. If we investigate the effects of an error of $\pm 0{\cdot}0001$ in one or more of the indices, we have twenty-six values, some or all of which differ from V. Computing for sodium-light from Tables VI and XII the values of $\frac{\partial V}{\partial \alpha}$, $\frac{\partial V}{\partial \beta}$, and $\frac{\partial V}{\partial \gamma}$, and assuming that the refractive indices are each affected by a difference of 0·0001, we obtain :—

	$\frac{\partial V}{\partial \alpha}d\alpha$	$\frac{\partial V}{\partial \beta}d\beta$	$\frac{\partial V}{\partial \gamma}d\gamma$
Adularia	18·9′	−1°12·5′	53·5′
Moonstone	17·9	−59·3	41·4

Hence we see that, if da, $d\beta$, and $d\gamma$ all have the same sign, $dV = 0$. On the other hand, when $d\beta$ is opposite in sign to the other two, dV has a maximum value: $\pm 2° 24·9'$ for adularia, and $\pm 1° 58·6'$ for moonstone. Therefore $2V$ may vary, according to the possible magnitudes (double $\pm 0·0001$) and signs of the errors in a, β, and γ, by as much as $9° 47·6'$ for the first, and $7° 54·4'$ for the second.

We see then that even very small errors in a, β, and γ may affect $2V$ to an extent out of all proportion to the error possible in a more direct determination of the angle. Let us suppose the value, $2V'$, found directly to be affected by an error of $\pm 10'$. The least error due to one of $\pm 0·0001$ in any of the indices for adularia or moonstone is seen to occur when da is the only one which is not zero, and to be $\pm 19' \times 2$ for one, and $\pm 36'$ for the other, very nearly four times the error assumed possible in $2V'$. Therefore, if $2V$ agrees with $2V'$ within the limits of $\pm 10'$, we conclude that there is no error in any of the indices exceeding $\pm 0·0001$, except when all three have the same sign and $dV = 0$.

If, however, the angle V be determined from the approximate formula $\tan^2 V = \dfrac{\beta - a}{\gamma - \beta}$, it is easy to show that the angle is unchanged by any equal errors of a, β, and γ. For on differentiation it is found that $\dfrac{\partial V}{\partial a} + \dfrac{\partial V}{\partial \beta} + \dfrac{\partial V}{\partial \gamma} = 0$.

For moonstone, the angle given by the exact tangent formula is $33° 10'$, by the approximate one $33° 19'$, and by direct observation $33° 12'$. This shows that in such a case the last formula gives a satisfactory result. Trial, however, shows that serious divergencies arise when the angle V approaches $45°$ or zero.[1]

[1] See F. E. Wright, 'Graphical methods in microscopical petrography.' Amer. Journ. Sci., 1913, vol. xxxvi, p. 509.

Chabazite and associated minerals from County Antrim.[1]

(*With Plates XI–XIV.*)

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[Read June 7, 1910, March 12, 1912, March 17, 1914.[3]]

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[1] Communicated by permission of the Trustees of the British Museum.

[2] Formerly F. N. A. Fleischmann.

[3] The following were the papers read before the Society: 'On zeolites from the neighbourhood of Belfast,' by F. N. A. Fleischmann, January 21, 1908; 'Phacolite from near Belfast,' by G. F. Herbert Smith, June 7, 1910; 'On the zeolites from Killyflugh and White Head, County Antrim,' by G. F. Herbert Smith and F. N. A. Fleischmann, March 12, 1912; 'On gmelinite and chabazite from Co. Antrim,' by G. T. Prior, March 17, 1914.

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I. Introduction.

EIGHT years ago (in 1907) Mr. F. N. Ashcroft, who for many years has devoted much of his leisure to bringing together choice specimens of the species included in the zeolitic group of minerals, turned his attention to the specimens occurring in the cavities of the basalt of Co. Antrim. He was fortunate enough to secure the services of Mr. Robert Bell, of Belfast, in his quest, and between them they have searched many of the quarries and other places likely to yield good specimens of these minerals. Some of the early specimens obtained through Mr. Bell, which, however, did not include any chabazite, were exhibited by Mr. Ashcroft at the anniversary meeting of the Society, on November 12, 1907. Among the specimens collected two years later were some from the Killyflugh quarry displaying well-formed, twinned crystals of phacolite, which Mr. Ashcroft submitted for examination to the Mineral Department of the British Museum. The character of the crystals and the nature of the mineral association proved to be of such interest that ultimately a systematic study of the specimens was undertaken. Nearly every year Mr. Ashcroft collected further specimens, and he has freely permitted the best of his collection to be used for the purpose of the investigation. Afterwards he presented to the Trustees of the British Museum a typical selection of the specimens collected at the localities described in this paper, including those actually examined in detail.

II. Topography (F. N. A.).

The specimens of chabazite and the minerals associated with it which are dealt with in this paper came from the three following localities, and mainly from the first of them; altogether nearly 200 specimens were examined.

1. *White Head, in the Barony of Lower Belfast.*

The promontory White Head (Plate XI), some 300 feet in height, lies on the northern shore of Belfast Lough at the point where it merges into the Irish Channel. It gives its name to the town Whitehead, a popular seaside resort lying to the north of it, much frequented by residents of Belfast. Specimens were collected from the quarries on both sides of the headland.

(a) *Quarry*[1] *on the North Side of White Head.*

This quarry (Plate XII) lies at the extremity of the headland just above the coastguard station at the southern end of the town of Whitehead, and forms a conspicuous scar on the north side of the headland. It was first visited by Mr. Ashcroft on November 22, 1907. His attention had shortly before been directed to the locality by Mr. Bell, who had collected and forwarded to him a number of specimens from the quarry, including several remarkable specimens of gmelinite.

The exposure in the quarry is interesting. Both chalk and basalt are exposed on the face, the former rising to a considerable height above the floor of the quarry at each side of the exposure, especially on the right-hand side of the quarry. The usual layer of earthy rubble with flints separates the chalk and the basalt. The lower part of the basalt is hard, compact, and rudely columnar in structure. It yields no zeolitic minerals, but very occasionally contains flakes of metallic copper. Above this is a thick layer of amygdaloidal basalt upon which rests a bed of boulder clay. On a bank below the level of the quarry floor close to the coastguard station there is an exposure of Greensand. It is from this mass of amygdaloidal basalt, which varies considerably in character, and undoubtedly consists of a number of different flows, that the greater part of the material collected is derived. Unfortunately

[1] According to the Home Office List of Quarries for 1913, published in 1914, this quarry is owned by Messrs. G. Gregg & Sons, Strathkeen, Larne.

the amygdaloidal layers are inaccessible; the specimens were collected from fallen boulders, and it is impossible therefore to state with accuracy their exact horizon.

In November 1907 Mr. Ashcroft collected a number of specimens of gmelinite, and in the following April obtained an additional large series of them by breaking up several large boulders, about 6 feet cube in size. The gmelinite occurs in dense, yellow or white crusts lining very irregularly shaped cavities in a highly decomposed basalt which are connected one with another by narrow seams and stringers. They often show signs of corrosion and are frequently associated with hemispherical, often hollow, aggregates composed of more or less altered natrolite[1] mixed with minute gmelinite crystals, or sometimes with analcite, or less commonly with calcite in modified acute rhombohedra. The gmelinite crystals themselves are usually not homogeneous, being clear and transparent in the outer portions, but opaque in contact with the matrix. Subsequently, similar, but more homogeneous crystals were found; analysis No. 2 (p. 297) was made on these. The smaller gmelinite crystals are often almost water-clear. Both twinned (about *r*, the usual gmelinite law) and simple crystals were met with, the former being by far the commoner. Occasionally two crops of crystals are present on the same specimen, comparatively large crystals lying in a carpet of small ones, and more rarely the crystals have been more or less dissolved and afterwards redeposited in the form of minute gmelinite crystals. The forms present are always *f* and *m*, which in small crystals are smooth, but in large ones marked, the former triangularly parallel to the edges with the two adjacent faces of the form and to the horizontal, and the latter horizontally, owing to twinning or to oscillatory growth. Very rarely is the base *c* present, and in the case of crystals from two specimens it gives reflections corresponding to the faces *r* and *e*, which belong to the phacolite habit. Three specimens of considerable interest showed complex crystals, the component individuals of which are connected by the usual gmelinite mode of twinning about *r*, but themselves belong to the phacolite habit, and display the forms *r* and *e* twinned about *c*.

In addition, a small series of specimens was obtained the matrix of which is distinctly harder and more compact than in the remainder. They

[1] J. Strachan, Proc. Belfast Naturalists' Field Club, 1908, ser. 2, vol. vi, p. 92, records the occurrence of natrolite at Whitehead, but does not specify the quarry.

resemble specimens obtained from the upper flow on the south side of the headland, and no doubt have come from part of the same flow. These specimens show simple and twinned crystals of gmelinite, associated with fibrous masses of natrolite. The material for analysis No. 1 was obtained from them.

A series of specimens were collected from what appears to be an old land-surface close to the chalk on the right-hand side of the quarry. The seams and cavities in the basalt are lined with a crust of tiny trapezohedra of analcite, mixed with small, fibrous clumps of natrolite and associated with opaque, white and yellowish crystals of gmelinite, often lenticular in shape owing to the rounding of the faces of the form *f*; a little nodular calcite also was seen.

According to Mr. Bell large radiating masses of natrolite were at one time obtainable in quantity from the upper amygdaloidal basalt, but have long since become scarce.

Among the specimens collected is one (in halves) of natrolite in fairly stout, radiating prisms, a few of which are terminated by faces; it has no matrix. Several groups of very thin radiating needles implanted on a matrix, similar to that in which the corroded gmelinite occurs, were also collected.

(b) *Quarry on the South Side of White Head.*

This quarry (Plate XIII), which has been abandoned for about twenty years, is situated on the south side of the headland immediately above the portal of the tunnel on the Belfast-Larne Railway piercing the headland, and is not far from the quarry just described. On the face of the quarry and the natural cliff above the quarry a large number of basalt flows are exposed, many of which are highly amygdaloidal. They are very irregular, and the thickness of any particular flow varies considerably over different parts of the quarry face. Often the vesicles are very small, and are solidly plugged with zeolitic material. The whole exposure is now in a very disintegrated and dangerous condition, and falls of rock are frequent. A particularly heavy fall, from high up on the face, took place early in 1910, after the photograph reproduced on Plate XIII was taken, and has covered a great part of the floor of the quarry to a considerable height, leaving only a narrow passage between the pile of boulders and the face of the rock.

Mr. Ashcroft first visited the quarry in April 1908, his attention having been drawn to it by Mr. Bell, and he collected a large number of

specimens on that occasion. They were obtained in situ, being extracted by means of crowbars from the bottom flow on the right-hand side of the quarry at the points indicated by the arrows marked *A* and *B* on Plate XIII. The flow is much decomposed, and varies considerably in colour; not infrequently a hand-specimen of the rock may be partly brick-red and partly grey in colour with a distinct line of demarcation between the two portions.

The cavities are irregular in shape and frequently angular, and vary considerably in size; one exposed on the surface, the contents of which were entirely destroyed by weathering, was at least 60 cm. across in one direction. The quarry was visited by Mr. Bell again a little later in the same year, and a similar series of specimens collected. The minerals represented included chabazite, which was found generally white, but occasionally pinkish in colour, both massive and in crystals; in the latter case, usually in the gmelinite habit, both simple and twinned, and less commonly in the form of the fundamental rhombohedron. The extremely interesting specimen showing small gmelinite crystals in correctly corresponding orientation on a comparatively large rhombohedron (fig. 1) discussed below (p. 289), was received by Mr. Ashcroft in June 1908. Chabazite occurred also in the form of pseudomorphs after calcite (p. 300). Analcite, which was found in the usual form of trapezohedra, lined the outside of the pseudomorphs referred to, and, if the latter were hollow, the inside also. Natrolite was present in the usual needle- or blade-shaped crystals springing out from analcite and chabazite.

Some interesting specimens were found by Mr. Ashcroft in 1909. On two specimens the crystals displayed the forms *r*, *e*, *s*, as in the phacolite habit, but were so intimately twinned as to appear hexagonal, as in the gmelinite habit, and each crystal was composed of individuals of this kind connected by twinning about *r*, the typical gmelinite law. In February 1914 a series of specimens were obtained from debris which had fallen from one of the upper flows; from which one is uncertain, although undoubtedly the whole series came from the same flow. The rock is much less decomposed and the cavities fewer and more regular in shape than in the case of the specimens previously collected. This series probably came from the same flow as a series collected on the other side of the headland, as was pointed out above (p. 278). These specimens exhibited gmelinite in very pale pinkish-yellow, usually twinned, crystals, and also massive, associated with a considerable amount of natrolite in sheaf-like groups; no analcite was observed.

2. *Killyflugh, in the Barony of Lower Toome.*

This basalt quarry,[1] which for want of an independent name may be conveniently called Killyflugh quarry, is situated about 700 yards north-east of the farm of Killyflugh in the townland of that name, some two miles to the north of the town of Ballymena. It is best reached from this town, by following the main road to Cushendall as far as the point, about 230 yards short of Crowdy Knowe farm and of the second mile-stone, where two roads branch off, the one north-north-west leading indirectly to Clogh Mills, and the other north-west; some 370 yards down the latter on the right-hand side of the road a small farm-house is reached, and immediately behind, i.e. to the north of it, lies the quarry in question.

The rock-face, as is clearly shown in the photograph reproduced in Plate XIV, fig. 2, consists of hard, compact basalt, which as yet has yielded no cavities containing zeolitic minerals. This flow rests on another consisting of a much decomposed and in parts highly porous basalt, from which the minerals collected were obtained. The contact between the two flows, which is usually invisible, is irregular, but approximately level with the floor of the quarry. Fresh material is consequently sometimes rather difficult to obtain, except when, owing to blasting operations in the lowest part of the rock-face, a hole some few feet in depth has been made exposing the lower flow, or where, as happens here and there, the contact between the two flows rises a few feet above the level of the floor of the quarry. The minerals found, viz. phacolite, analcite, and occasionally mesolite, occur, as far as can be judged, throughout the flow, but the general aspect of the specimens obtained from different points in the quarry varies considerably.

The first specimens obtained were collected, in July 1908, by Mr. Bell from a hole, due to blasting, in what was then the southern corner of the quarry, which two days later was water-logged and shortly afterwards filled in with waste rubble, and also from a small mound opposite the face of the quarry. At the first point the minerals occur lining or completely filling narrow cracks and angular cavities connected with them. In some specimens the rock in immediate contact with the cavities is practically a breccia, consisting of angular fragments of basalt cemented together by the zeolitic minerals. When freely developed,

[1] According to the Home Office List of Quarries for 1913, published in 1914, this quarry is owned by Mr. S. Herbison, of Killyflugh, by whom it is worked for road-metal.

phacolite occurs in large, pale-yellowish crystals, which are sometimes in groups and sometimes isolated; they are associated with colourless analcite crystals, about 2–3 mm. in diameter, which form a continuous crust between the phacolite crystals, and sometimes with fine hairs of mesolite, and more rarely with a little calcite. It was from this point that the material used in the chemical analysis, No. 5 (p. 297), came. On the other hand, the phacolite crystals obtained from the mound, a low grass-grown hummock, were colourless to greyish in tint, and rather similar to, though not so large or so regularly developed as, those found later; they were associated with mesolite, and occurred in irregularly shaped cavities in a much weathered and extremely friable basalt.

On June 8, 1909, Mr. Ashcroft and Mr. Bell collected a large number of specimens from a hole, made by a blast the previous day, which was situated approximately at the foot of the centre of the rock-face. Here much of the rock was extremely porous, and the cavities were often large and very irregular in shape. Phacolite occurred in great quantity in large, greyish crystals scattered singly or in groups all over the walls of the cavities together with minute (about 1 mm. in diameter) isolated crystals of analcite. The walls of the cavities were coated with a very thin, whitish film of kaolin, on which the crystals of phacolite and analcite were superimposed. The crystals of phacolite were remarkable not only for their size and complexity of form (p. 291), but for the fact that only the thin outer shell consists of pure phacolite; internally they are choked with filaments and fragments of the matrix.

The same type of phacolite crystal was collected on many subsequent visits at various points of the quarry. Unfortunately the rock is much decomposed, and the specimens are very liable to crumble away on keeping.

From deep down in the hole just mentioned, about 4 feet below the level of the floor of the quarry, several specimens of a somewhat different type were collected. The matrix, which is rather harder, is studded with small, colourless crystals of phacolite of a simpler habit (p. 290); it also is coated with a thin film of kaolin, which, however, is yellowish in colour. This type, however, could not be seen in situ because of the mass of rubble in the hole.

Early in 1912 Mr. Bell excavated at the foot of another grass-grown mound opposite the centre of the quarry-face, and obtained, in addition to a number of specimens showing phacolite in large, grey crystals, a few

specimens in which the matrix was comparatively hard and solid, and the surface of the cavities was coated with a thin, yellowish film of kaolin studded with large, isolated crystals and groups of phacolite of a deep-yellow colour, together with small, colourless crystals of analcite.

3. *Craigahulliar, in the Barony of Carey.*

Some zeolitic minerals were found in the cutting (Plate XIV, fig. 1),[1] constructed a few years ago to carry the truck line to connect the quarry[2] on Craigahulliar, a small cliff the face of which is practically entirely occupied by the quarry, with the main road between Portrush and Bushmills. The cutting was made subsequent to the six-inch Ordnance Survey, and consequently does not appear on the map of the district. The truck line joins the main road mentioned about $1\frac{3}{4}$ miles from Portrush, and the entrance to the cutting lies about a third of a mile down the line. The greater part of the cutting, which is about 200 yards long, is situated in the townland of Cloughorr, but a small portion at the southern end is in the townland of Craigahulliar. The boundary between the two townlands runs along the north side of the road between Upper Burnside and Lower Ballymagarry, which crosses the cutting by a bridge a few yards from the southern end.

The cutting was visited by Mr. Ashcroft first on July 19, 1912, and again in May 1913. Along the sides a number of distinct flows, dipping to the south, were well exposed in 1912, but less so in 1913, by which date the sides were fast becoming covered with loose earth and rubble, and in parts overgrown. In one of these flows, consisting of much-decomposed basalt, which is exposed about 20 to 30 yards north of the bridge, phacolite occurs in quantity; but good specimens were rather difficult to obtain owing to the rapid weathering of the surface and the refusal of the Company to allow the banks of the cutting to be interfered with. The crystals were white or yellowish in tint, and often large in size; they were sometimes associated with calcite. A considerable number of the specimens collected were obtained from the sides of a low embankment, about two or three feet high, which carries the truck line

[1] Mr. Robert Bell, the collector, may be seen standing in the cutting.

[2] According to the Home Office List of Quarries for 1913, published in 1914, this quarry is owned by the Giant's Causeway Columnar Basalt Co., Portrush. The basalt of the quarry, part of which is finely columnar in structure, belongs to the Upper, while that exposed in the cutting belongs to the Lower Basalt Series. At the base of the rock-face and again just above an old iron-mine adit, a few yards to the east of the quarry, a bed of lignite is visible.

between the cutting and the quarry, and from a small dump. There can, however, be no question that this material originally came from the flow mentioned above.

III. Chabazite (Phacolite, Gmelinite).

A. *Historical.*

The name adopted for this mineral group is due to Bosc d'Antic, who gave the name *chabazie*, of somewhat fantastic origin,[1] to the crystals from Oberstein, but it was Haüy[2] who definitely separated chabazite from analcite by showing that what had been taken for cubes were really rhombohedra with interfacial angle of 86° 12′.[3] Subsequently, in consequence of differences in crystalline form or in physical characters, additional names were proposed for minerals of similar chemical composition, such as phacolite,[4] herschelite,[5] gmelinite,[6] and levyne.[7] Among the older writers of mineralogy, Tamnau[8] considered these minerals to be one species; Breithaupt[9] included phacolite, gmelinite, and levyne as species of the genus chabazite; while Hausmann[10] merged them together as a single species. Rose,[11] on the other hand, left phacolite with chabazite, but separated gmelinite and levyne from it on account of the difference in cleavage and crystalline form. Streng,[12] however, in his elaborate memoir on chabazite argued that gmelinite and levyne were merely varieties of it, because no distinction could be drawn between them in respect of chemical composition, and because the fundamental forms were very simply related to one another. Coming to more recent

[1] 'tiré d'un mot grec, qui désignoit une certaine espèce de pierre,' Journ. d'Hist. nat., 1788, vol. ii, p. 181.

[2] R. J. Haüy, 'Traité de Minéralogie,' 1801, vol. iii, p. 176.

[3] This angle was determined by means of the contact-goniometer, and differs by about a degree from the accepted value, viz. 85° 14′, which was given by W. Phillips in his 'Mineralogy,' 3rd edition, 1823, p. 138.

[4] A. Breithaupt, Neues Jahrb. Min., 1836, pp. 653, 657.

[5] A. Lévy, Ann. Phil., 1825, new ser., vol. x, p. 361.

[6] D. Brewster, Edinburgh Journ. Sci., 1825, vol. ii, p. 262.

[7] D. Brewster, ibid., p. 332.

[8] F. Tamnau, Neues Jahrb. Min., 1836, p. 658.

[9] A. Breithaupt, 'Vollständiges Handbuch der Mineralogie,' 1847, vol. iii, p. 416.

[10] J. F. L. Hausmann, 'Handbuch der Mineralogie,' 1847, pp. 780, 1600.

[11] G. Rose, 'Krystallo-chem. Mineralsystem,' 1852, pp. 97, 99, 102.

[12] A. Streng, 'Ber. Oberhess. Ges. Nat.- Heilkunde, 1877, pp. 74–123.

times we find that Dana in the sixth edition of his 'System of Mineralogy,' published in 1892, follows Rose, and under gmelinite remarks 'notwithstanding the close relation of the two species [gmelinite and chabazite] it is most unnatural to merge them in one.' In the second and third editions, published respectively in 1844 and 1850, he had adopted the views of Tamnau as to the identity of these supposedly different species, but in the fourth, published in 1854, and subsequent editions he made gmelinite and levyne distinct species. Hintze [1] likewise places phacolite with chabazite and ranks gmelinite and levyne as sub-species.

B. *Physical Properties.*

(a) *Crystal Measurements.*

The present investigation has tended to confirm Tamnau's conclusion that gmelinite is but a variety of chabazite and not a distinct species; no crystals corresponding to levyne were met with. The name chabazite is therefore applied to the whole group, and it is convenient to retain the term gmelinite for the apparently hexagonal crystals, and to use the term phacolite in a somewhat widened sense for all the crystals, invariably twinned, of rhombohedral habit, and not merely for those lenticular in shape. The unit rhombohedron adopted in this paper is r, the primary rhombohedron of phacolite. Goldschmidt [2] selected as unit the rare rhombohedron form t, without, however, any general simplification of the indices of the faces.

In the following table are included the well-defined forms that were observed; four of them occurred on phacolite and three on gmelinite.

Table I—Principal Observed Forms.

Phacolite	r (10$\bar{1}$1)	The most prominent form on phacolite and the plane of twinning for gmelinite; the plane of cleavage on phacolite. Faces usually striated owing to the mutual interference during growth of the component individuals of a twinned crystal.

[1] C. Hintze, 'Handbuch der Mineralogie,' 1897, vol. ii, pp. 1769–1792.

[2] V. Goldschmidt, 'Krystallographische Winkeltabellen,' 1897, p. 91. The forms of gmelinite are included under chabazite (cf. p. 406). See also 'Atlas der Krystallformen,' 1913, vol. ii, p. 125.

Phacolite	e (01$\bar{1}$2)	A common form, but generally relatively small. Smooth or slightly striated, and gave usually distinct reflections.
„	s (02$\bar{2}$1)	Not so common as the preceding. Small, but smooth, and gave good reflections; sometimes showed multiple images.
„	a (11$\bar{2}$0)	Small, and rather rare.
Gmelinite	f (20$\bar{2}$3)	The characteristic form of gmelinite. Faces smooth on small crystals; otherwise triangularly marked parallel to the edges bounding them.
„	m (10$\bar{1}$0)	Not so persistent as the preceding and varied considerably in relative size. Faces usually striated horizontally. The plane of cleavage on gmelinite.
„	c (0001)	Rare. The plane of twinning of phacolite. Reflections indistinct, and sometimes correspond to faces of the forms r and e.

In the case of the interpenetrating twinned crystals of phacolite the zones connecting the faces of the form r (10$\bar{1}$1) were considerably striated. Usually numberless images corresponding to vicinal faces were grouped so close together as to afford in the field of the goniometer an almost continuous band over a considerable arc. Brighter images testified to the tendency to the formation of certain definite faces, such as y (71$\bar{8}$9), χ (51$\bar{6}$7), θ (41$\bar{5}$6), ϕ (31$\bar{4}$5), z (52$\bar{7}$9), o (21$\bar{3}$4), and t (11$\bar{2}$3), the most prominent being θ and ϕ. Sometimes the rhombohedron face was replaced almost entirely by these subsidiary faces (cf. figs. 2 and 3).

None of the crystals examined was developed in such a way as to afford really trustworthy measurements of the angular co-ordinates, and implicit reliance cannot be placed on the values obtained. Most of the crystals were rather too large for convenient manipulation on the goniometer, and the faces of any crystals of such sizes are invariably more or less distorted. But even on the tiny, water-clear crystals of gmelinite from the quarry on the north side of White Head the faces generally gave rise to more than one image, and it was impossible to decide which was the best reading. Evidently under the present conditions the crystals have been subject to considerable strain, and their rigidity has

not been sufficient to enable them to withstand it. The pole of symmetry *c* (0001) was taken as the origin of measurements. The face itself occurred on very few crystals, and even in such cases the reflection given was far too diffuse and dull to be used. The pole had therefore always to be determined indirectly. Generally there were alternate methods of doing so. Thus, supposing the form *r* were utilized, the position of the pole of symmetry might be determined as the position which gave identical polar distances of three faces of the form, or the zone [*crsm*] might be adjusted so that its edge was parallel to the axis *C* of the three-circle goniometer, and the pole in question found from the readings for the faces of the forms *r* on different individuals of the composite crystal. Again, the prism-zone, if sufficiently well developed, might be used, but this rarely happened. The form *m* (10$\bar{1}$0) was better developed, and occurred oftener than *a* (11$\bar{2}$0), but it was always striated horizontally—precisely the wrong direction for the purpose in view—so much so, that the zone could not be adjusted with any approach to certainty. In the case of the twinned crystals, however the pole may have been determined, the observations on the crystal were invariably discordant—an indication of distortion. For instance, faces which should theoretically have been in some particular zone lay a degree or two away from it; this peculiarity was very noticeable in the case of the twinned crystals of phacolite. The angular co-ordinates of the faces of any form differed considerably, even on the same crystal, and the polar distances observed for *e* (01$\bar{1}$2) and *s* (02$\bar{2}$1) often differed markedly from the values deduced by calculation from the polar distance measured in the case of *r*.

The obvious question suggested itself—was the difference in habit between phacolite and gmelinite accompanied by a marked change in the fundamental angle? A review of the measurements of crystals from the quarries at White Head—since gmelinite was only met with at this locality—revealed no signs of an alteration in the angle. Thus, in the case of phacolite it varied from 50° 53′ to 52° 2′, and in the case of gmelinite from 51° 1′ to 52° 10′. Taking into consideration the comparatively untrustworthy nature of the measurements, the range in each instance was the same. In the case, however, of a small, simple, glassy crystal of gmelinite from the quarry on the north side, which yielded unusually definite reflections, the following values were observed for the polar distance of *f*: 39° 57′, 40° 11′, 40° 13′, 40° 13′, 40° 15′, 40° 16′; the mean value is 40° 11′, and the corresponding value of *cr* 51° 43′. Another crystal—an extremely tiny one—from the same

quarry was set up by means of the prism-faces, and the following values observed for the polar distance of *f*: 40° 4′, 40° 6′, 40° 7′, 40° 8′, 40° 39′; mean value 40° 13′, *cr* calculated 51° 45′. It is possible, therefore, that the fundamental angle is slightly larger for the gmelinite than for the phacolite type of crystal. The six best crystals measured from Killyflugh gave the following values for *cr*: 50° 45′, 50° 59′, 51° 3′, 51° 3′, 51° 4′, 51° 20′, and the corresponding values for the three best crystals from Craigahulliar were 50° 35′, 50° 44′, 51° 10′. If we take the mean of the fundamental angles determined for the best crystals measured, thirty in number, we obtain the value of 51° 27′, which agrees closely with the accepted value (51° 26′) for chabazite calculated from the rhombohedral angle 85° 14′ (94° 46′) given by Phillips.[1] The fundamental angle, *cf*, of gmelinite to be found in present-day textbooks is that given by Pirsson[2] for crystals from Nova Scotia, viz. 40° 18′, the corresponding angle *cr* being 51° 50′. Des Cloizeaux[3] obtained almost identical values for chabazite and gmelinite, viz. 51° 26′ and 51° 29′ (*cf* 39° 57′), respectively.

In the following table are given the angular co-ordinates of the principal observed forms calculated from the fundamental angle $cr = 51° 26′$.

Table II—Angular Co-ordinates of the Principal Forms.

($a : c = 1 : 1{\cdot}0860$.)

	ϕ	ρ
$-e$ $(01\bar{1}2)$	0° 0′	32° 5′
$-f$ $(02\bar{2}3)$	0 0	39 54
r $(10\bar{1}1)$	0 0	51 26
$-s$ $(02\bar{2}1)$	0 0	68 16
m $(1\bar{1}0\bar{1}0)$	0 0	90 0
y $(71\bar{8}9)$	6 35	46 27
χ $(51\bar{6}7)$	8 57	44 55
θ $(41\bar{5}6)$	10 53	43 45½
ϕ $(31\bar{4}5)$	13 54	42 7
z $(52\bar{7}9)$	16 6	41 1½
o $(21\bar{3}4)$	19 7	39 39
t $(11\bar{2}3)$	30 0	35 54
a $(11\bar{2}0)$	30 0	90 0

[1] W. Phillips, 'Mineralogy,' 3rd edition, 1823, p. 138.
[2] L. V. Pirsson, Amer. Journ. Sci., 1891, vol. xlii, p. 57.
[3] A. Des Cloizeaux, 'Manuel de Minéralogie,' 1862, vol. i, pp. 408, 397.

The values observed for *e* and *s* differed noticeably from those given above. Thus, in the former instance the mean values observed for the best crystals were 31° 50′, 32° 10′, 32° 20′, 32° 20′, 32° 21′, 32° 28′; 32° 30′, 32° 34′, 33° 8′; the mean value, 32° 25½′, is too high, and, indeed, in only one case was the observed mean below the calculated value given in the table. In the latter instance, the corresponding values were 67° 12′, 67° 14′, 67° 14′, 67° 17′, 67° 28′, 67° 33′, 67° 43′, 67° 46′, 67° 46′; the mean value 67° 28′ is too low, and none of the observed means was above the calculated value. The following table includes examples of measurements made in the striated zones:

Table III—Observations made in Striated Zones.

ϕ	ρ	ϕ	ρ	ϕ	ρ
2°54′	49° 7′	10°47′	43°58′	15°31′	42° 0′
2 57	49 10	10 57	44 4	15 43	41 23
3 45	54 47	11 7	44 5	15 58	41 20
4 1	49 3	11 20	43 50	15 58	41 22
4 5	39 37	11 22	43 39	17 2	39 37
4 59	48 10	11 22	44 0	17 30	41 49
5 0	47 35	11 35	43 45	17 52	38 15
5 14	47 32	11 40	43 16	18 35	40 35
5 25	47 31	11 43	43 0	18 36	40 9
5 37	47 30	11 45	44 11	19 3	39 57
5 53	47 0	11 48	43 30	19 27	39 50
5 53	48 12	12 23	43 6	19 58	43 1
6 16	46 58	12 29	43 50	20 30	39 40
6 34	46 41	13 7	42 45	21 25	36 20
7 5	46 30	13 30	42 50	24 20	33 0
7 7	44 38	13 49	42 21	25 37	37 39
7 25	45 45	13 52	42 40	26 25	36 10
7 37	45 56	13 59	42 40	26 40	37 37
7 40	46 1	14 17	42 30	30 0	35 45
7 47	45 56	14 22	42 19	30 0	36 0
7 50	45 10	14 30	42 0	30 0	36 6
8 30	45 13	14 38	41 0	30 0	36 25
9 3	45 0	14 40	42 22	30 0	36 45
10 18	43 37	14 57	41 45	30 0	36 48
10 28	43 55	15 22	41 58	30 0	36 55
10 35	44 25	15 30	42 50		

Occasionally vicinal faces near *e* were observed.

(b) *Habit.*

In discussing the various types of habit of the crystals it is convenient to divide them into the following groups, but it must be understood that each grades into the next and no sharp distinction can be drawn between them.

1. *Primitive Rhombohedron.*

Crystals characterized by the unmodified rhombohedron were very rare, and only five specimens containing such crystals were seen; all of them were collected at the quarry on the south side of White Head in the year 1908. The crystals, which are always twinned about *c*, are mostly small, under 1 mm. across, and their faces are comparatively smooth and entirely free from striations.

The crystal illustrated in fig. 1 is particularly interesting. It consists mainly of a rhombohedron of chabazite, measuring about 2·5 mm. in length with two smaller ones intersecting it in twin position, the faces of which are coated with tiny crystals of gmelinite arranged in parallel position and correctly orientated with respect to it. The number of

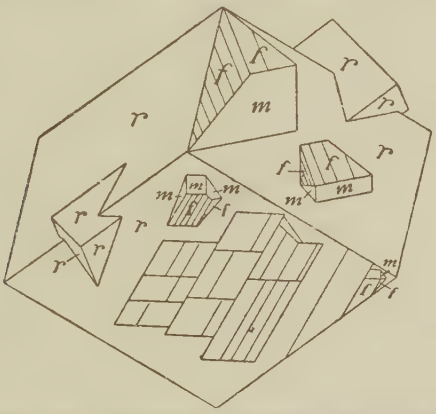

Fig. 1.—Chabazite rhombohedron twinned about *c*, with Gmelinite in parallel position. From the bottom basalt flow in the quarry on the south side of White Head.

gmelinite crystals was far larger than could conveniently be shown in the drawing. Part of one face, as may be seen from the figure, is largely covered with an intergrown mass of gmelinite which gave reflections corresponding to the forms f $(02\bar{2}3)$ and m $(10\bar{1}0)$. The mean value of the values of the polar distance determined for the faces r was 51° 15′, and for f 40° 1′. The value for cf calculated from $cr = 51° 15'$ is 39° 43′, which is in satisfactory agreement with that observed, considering the comparatively rough character of the measurements. No other crystal of the kind was noticed. A similar crystal from Ireland, the precise locality not being stated, was described and figured by Brooke.[1] The polar distances

[1] H. J. Brooke, Phil. Mag., 1837, vol. x, p. 278.

calculated from the angles given by him are for r 51° 26′ and for f 40° 0′, which are close to those stated above.

2. *Modified Rhombohedra.*

This type lies intermediately between Nos. 1 and 3. Six edges of the primitive rhombohedron are bevelled by faces of the form e (01$\bar{1}$2), and

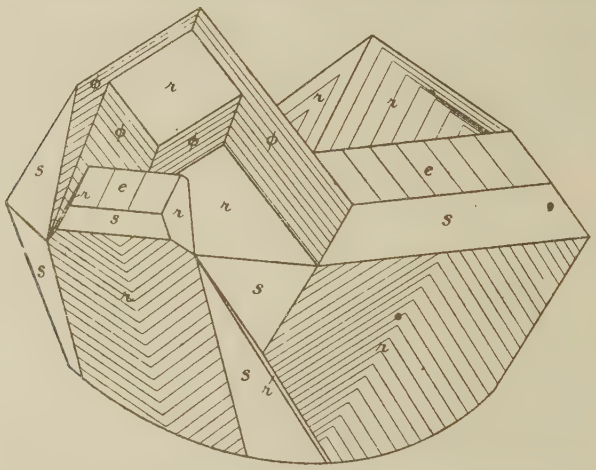

Fig. 3.—Chabazite, rich in forms, twinned about c. From Killyflugh.

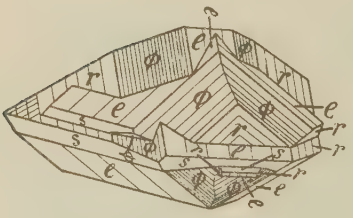

Fig. 2.—Modified rhombohedra from Killyflugh.

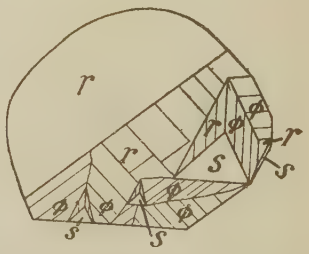

Fig. 4.—Twinned crystal from Craigahulliar.

the form s (02$\bar{2}$1) is often present. The crystals are invariably twinned about c, and the component individuals are to some extent interpenetrant, but not so completely so as in the next type.

This type was very abundant, especially at Killyflugh. At this locality the crystals are small, about 1–2 mm. across, and somewhat yellowish in

tint. The faces *e* (fig. 2), which are relatively prominent, are slightly striated; those of *r* considerably striated parallel to the respective intersections with the contiguous faces *e*, i.e. in zones [*rer*] and often distorted; while the faces *s*, which are small, are comparatively smooth. Often the distortion of the faces *r* has been so great as to lead to their partial replacement by faces such as ϕ ($31\bar{4}5$). Fig. 3 represents a crystal of this kind from Killyflugh. Others of this type were found at Craigahulliar. One of them, which is shown in fig. 4, is interesting because it illustrates so clearly the disturbing effect on the development of the faces *r* caused by the emergence of a twin individual; where there is no emergence the face is comparatively smooth and free from striations, but the emergence of a twin individual causes a humping round the spot and considerable oscillation spreading from it.

A few crystals of this intermediate type were also met with at the quarry on the south side of White Head.

3. *Interpenetrating Twinned Rhombohedra.*

This, the true phacolite habit, is extremely common, and innumerable crystals of the type shown in fig. 5 were met with. They are comparatively large in size, measuring usually about 10–15 mm. in diameter. The principal occurrence was at Killyflugh, where characteristic crystals were found in great abundance. As was pointed out above (p. 281), they are remarkable for the fact that the whole of the interior is composed of fragments of basalt, only the outer shell, which is extremely thin, consisting of pure phacolite. The habit of the crystals is usually of the kind illustrated in fig. 5 (p. 292). The larger individuals composing the crystal are mutually bounded by planes parallel to the base and to faces of the form *m* ($10\bar{1}0$), but each individual is pierced by a varying number of smaller individuals orientated in twin position with respect to it. Occasionally the interpenetration is so intimate and regular that the development becomes pseudo-hexagonal in character. The gnomonic projection of the light-figures formed by the reflection of a pin-hole on the goniometer is depicted in fig. 6. Two bands of light intersect in each pole, representing a face of the form *r* ($10\bar{1}1$). In one direction each band soon comes to an end, but in the other it wanes and brightens here and there, particularly in the position corresponding to ϕ ($31\bar{4}5$), and finally disappears. A little farther on we come to a band extending on either side of the pole *e* ($01\bar{1}2$). The phenomenon just seen is repeated on the other side. As was remarked on p. 285, other forms in this

striated zone, such as y (71$\bar{8}$9), χ (51$\bar{6}$7), θ (41$\bar{5}$6), z (5279), o (21$\bar{3}$4), and t (11$\bar{2}$3), were also observed. The reflections given by the faces of the form s (02$\bar{2}$1), though never absolutely distinct, were only slightly banded, at right angles to the zone [cs]. The faces of the principal rhombohedron are invariably striated parallel to the rhombohedron edge, and oscillation, which is undoubtedly stimulated, if not directly caused, by twinning, is always present to a greater or less degree. The prism-faces, which are not common, are small, but comparatively smooth.

Crystals of somewhat similar habit, but rather less translucent, and without the basalt kernel, occurred in the quarry on the north side of

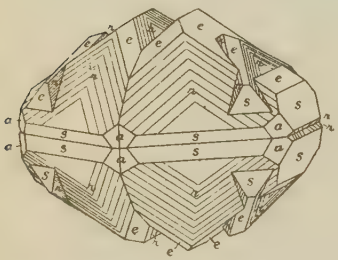

Fig. 5.—Phacolite, twinned about c, from Killyflugh.

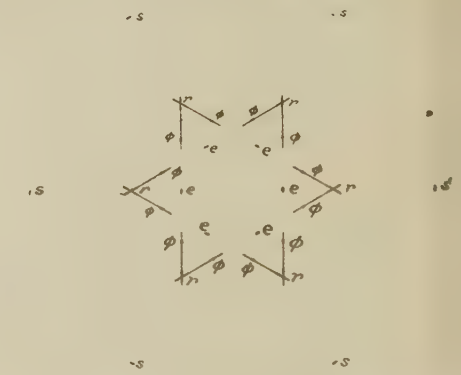

Fig. 6.—Gnomonic projection of Light-figures of Phacolite from Killyflugh.

White Head, and at Craigahulliar; at the latter locality they pertained more to the intermediate type described above. No crystals of the phacolite habit were found on specimens from the quarry on the south side of White Head.

4. *Double Twinning about* c (0001) *and* r (10$\bar{1}$1); *Oscillatory Crystals.*

On two specimens, of which the one came from the quarry on the north, and the other from that on the south side of White Head, remarkable crystals were observed which consisted of individuals displaying the characteristic forms of phacolite, viz. r (10$\bar{1}$1), e (01$\bar{1}$2), and to a smaller degree s (02$\bar{2}$1), together with the customary twinning about the axis c, but severally united by further twinning about r (10$\bar{1}$1), which is the characteristic mode of gmelinite. A crystal of this kind

from the quarry on the north side is depicted in fig. 7. Each of the two individuals shown is twinned about its own axis c, the subsidiary individuals being intimately interpenetrant, while they are mutually connected by twinning about those faces of the form r (10$\bar{1}$1) which are contiguous in the figure; the two faces are parallel. The faces of both the forms r and e are heavily striated parallel to the respective rhombo-

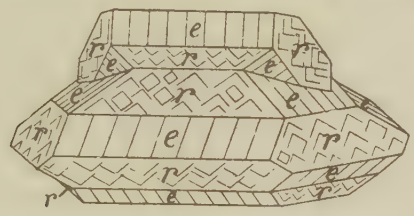

FIG. 7.—Two individuals related by twinning about r, each being twinned about c. From the north side of White Head.

hedron edges, and some oscillation between the faces of the two forms occurs. On the crystal represented other individuals were observed which were related to the lower one by twinning about other faces of

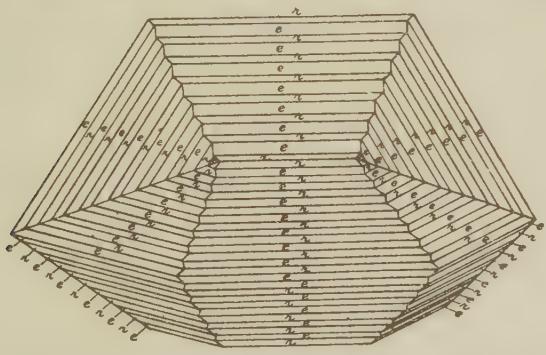

FIG. 8.—Two individuals related by twinning about r, each showing oscillatory twinning about c. From the north side of White Head.

the form r, but, in order to avoid confusing the drawing, they have not been shown. Fig. 8 represents another crystal from the same locality. In this case the twinning about the axis c in each individual is so oscillatory that each face is ribbed in character, and the development simulates hexagonal symmetry. If, in accordance with Haüy's theory of the formation of secondary faces, we imagined the steps to diminish in

size until they become comparable with molecular dimensions, we should expect the resulting crystal to be apparently hexagonal in symmetry, and to have the faces of the form intermediate between r (10$\bar{1}$1) and e (10$\bar{1}$2), which is f (20$\bar{2}$3), the characteristic form of gmelinite. The type here described may therefore be considered as transitional between phacolite and gmelinite, having the forms and modes of twinning characteristic of both.

The crystals off the specimen from the quarry on the south side are a little different, though of the same character. At first sight they might be supposed to be ordinary hexagonal crystals with six prism-faces and corresponding pyramid-faces above and below; but, on examining them, it was seen that the prism-faces are really oscillatory combinations of the forms r (10$\bar{1}$1) and s (02$\bar{2}$1), while the pyramid-faces belong to the form r, and the several individuals are connected by twinning about the faces of this same form. There is the same intimate twinning about the axis c, but the plane of combination seems to be parallel to r instead of to the base as previously. If again we imagined the steps diminished in size until commensurable with molecular dimensions, the reciprocation of the forms r (10$\bar{1}$1) and r (10$\bar{1}\bar{1}$) leads to the prism-form m (10$\bar{1}$0), and we should anticipate the resulting face to be striated horizontally: this, we shall see below, is the case with gmelinite.

5. *Simple Hexagonal.*

In this—the typical gmelinite—habit the crystals are characterized by a hexagonal prism-form m (10$\bar{1}$0) and six pyramid-faces of the form f (20$\bar{2}$3) above and six below. The latter faces are usually smooth, but are occasionally triangularly marked parallel to their edges. The prism-faces are always striated horizontally.

A large number of such crystals, associated with analcite and natrolite, were found on specimens from the quarry on the south side of White Head. They were usually white, but occasionally pink in colour, and were sometimes corroded. Similar crystals came from the quarry on the north side. On some crystals the prism-faces were relatively unusually large. Some interesting crystals were found on one specimen. They apparently displayed, in addition to the usual forms f (02$\bar{2}$3) and m (10$\bar{1}$0), the basal plane; but examination on the goniometer showed that the reflections from it corresponded to the forms r (10$\bar{1}$1) and e (01$\bar{1}$2). The specimens from the old land-surface contained a number of small, opaque, simple crystals.

6. *Twinned Hexagonal.*

The last group of all is composed of the gmelinite type of crystal twinned about the primitive rhombohedron of chabazite. Twinning of this mode is exceedingly common on the crystals occurring on the specimens from the quarries on both sides of White Head.

Since, corresponding to each individual of a twin, there are two sets of three poles *r*, or six altogether, there may be this number of individuals arranged in twin position with respect to it, and there may further be twinning about the poles of the second set of individuals; repeated twinning of this kind is common, and consequently the crystals met with are most complex in character. Fig. 9 represents a crystal off

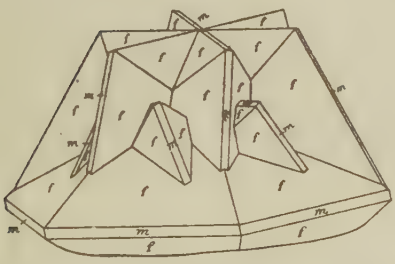

Fig. 9.—Gmelinite (forms *fm*) twinned about *r*. From the south side of White Head.

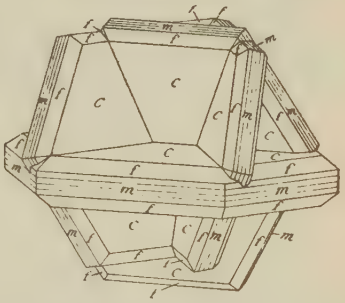

Fig. 10.—Gmelinite (forms *cfm*) twinned about *r*. From the north side of White Head.

a specimen from the quarry on the south side of White Head. Two sets of twin individuals are shown, the smaller set emerging at the angles between the larger set. The actual crystal showed in addition still smaller individuals in positions corresponding to repeated twinning, but, in order not to cause hopeless confusion in the drawing, they were not inserted. Fig. 10 represents a slightly different crystal which was taken from a specimen from the quarry on the north side. It is noteworthy for the remarkable development of the basal plane in each individual. One set of twin individuals only is shown in the drawing; the companion set occurred on the crystal, but they were very subordinate in size, and any attempt to include them would have unduly complicated the drawing.

(*c*) *Cleavage and Optical Properties.*

Crystals of the phacolite or rhombohedral type show a distinct cleavage parallel to the faces of the primitive rhombohedron *r* (10$\bar{1}$1) and another rather less distinct parallel to the prism *m* (10$\bar{1}$0). The latter cleavage alone, although somewhat more distinctly, is shown by crystals of the gmelinite or pseudo-hexagonal type.

In no instance was the development of the crystals such as to permit of accurate determination of the refractive indices. The double refraction in the phacolite type is very small, probably not more than one or two units in the fourth place of decimals; in the gmelinite type, however, it appears to be a little higher. Measurements with a small refractometer were made on a face polished on a crystal of the phacolite type, and the value 1·490 was obtained for sodium-light; no sign of doubling of the shadow-edge, indicative of double refraction, was observable. In the case of a crystal of the gmelinite type treated in the same way some doubling was discernible, and the extraordinary and ordinary indices of refraction were determined to be 1·480 and 1·490, the double refraction being negative in character.

C. *Chemical Composition* (G. T. P.).

Chemical analyses were made on exceptionally pure crystalline material picked out by Mr. Ashcroft from three occurrences of gmelinite and two of phacolite, viz.:

(1) Gmelinite: colourless crystals from one of the flows above the columnar basalt in the quarry on the north side of White Head.

The rock is an olivine-basalt of somewhat doleritic habit. Olivine is the only porphyritic constituent. The phenocrysts have good crystal outlines, but are all altered, as are also the olivine grains in the matrix, to green and deep-red decomposition products. The felspar is in laths and is partially altered to epidote. The augite, which is of a pale-purplish titaniferous variety, occurs in ophitic patches enclosing and penetrated by the felspar laths.

(2) Gmelinite: yellowish crystals from the quarry on the north side of White Head.

The rock in the cavities of which the crystals occur is much finer grained than No. 1, but is similar in other respects. Olivine is the only porphyritic constituent and is all altered. The phenocrysts occur in

a matrix of needle-like felspar laths, augite grains, altered glass, and skeleton crystals of magnetite.

(3) Gmelinite: very pale pinkish-yellow crystals from one of the upper flows of basalt in the quarry on the south side of White Head.

The rock is practically identical in characters with the basalt (No. 1) on the north side of White Head.

(4) Phacolite: colourless crystals from the cutting on Craigahulliar.

The basalt, which, though slightly finer grained, is otherwise almost precisely similar to Nos. 1 and 3 from White Head, consists of altered porphyritic olivine in a matrix of felspar laths, olivine grains, and ophitic patches of pale-purplish augite.

(5) Phacolite: pale-yellowish crystals from the basalt on the left hand in the southern corner of Killyflugh quarry.

The basalt is somewhat similar to that of White Head (No. 1), but is finer grained and less porphyritic. Olivine is all altered, the felspar is in small laths, and the augite is purplish, but occurs in grains instead of in ophitic patches.

The results of the analyses, which were made on air-dried material, are as follows:

	1.	2.	3.	4.	5.
SiO_2	46·64	46·75	47·81	48·61	48·82
Al_2O_3	20·04	19·79	19·73	18·06	18·53
CaO	7·00	8·25	5·01	8·19	8·81
SrO	0·22	0·23	0·02	0·60	0·26
K_2O	0·63	0·33	0·31	2·13	1·20
Na_2O	3·81	2·17	6·13	0·33	0·37
H_2O	21·84	22·09	21·56	21·68	22·09
	100·18	99·61	100·57	99·60	100·08
Sp. Gr.	2·09	2·07	2·06	2·09	2·09

The molecular ratios are as follows:

1.	2.	3.	4.	5.
0·7735 or 3·96	0·7753 or 4·13	0·7929 or 4·13	0·8061 or 4·48	0·8096 or 4·54
0·1961 ,, 1	0·1936 ,, 1·03	0·1930 ,, 1	0·1767 ,, 0·98	0·1813 ,, 1·02
0·1248, 0·0021, 0·0067, 0·0615 ,, 1	0·1471, 0·0022, 0·0035, 0·0350 ,, 1	0·0894, 0·0002, 0·0033, 0·0989 ,, 1	0·1461, 0·0058, 0·0226, 0·0053 ,, 1	0·1571, 0·0025, 0·0127, 0·0060 ,, 1
1·2132 ,, 6·22	1·2271 ,, 6·53	1·1977 ,, 6·24	1·2043 ,, 6·70	1·2271 ,, 6·88

The weights used in the analyses were about 1 gram for the main analysis, 0·5 gram for the alkalis, and 0·3 to 0·4 gram for the water determinations. The specific gravities were made on about 1 gram of material by means of a 3 c.c. pyknometer.

The analyses of gmelinite show a predominance of soda over potash as compared with those of phacolite, but this has probably no significance as a distinction of species, since the same predominance is shown by analyses of herschelite and seebachite of which the crystals are of typically phacolite habit.

As regards chemical composition the molecular ratios exhibit the same peculiarities which have been noted particularly in the case of nepheline and analcite. Whereas the ratio of alumina to the combined lime and alkalis conforms closely to equality, that of the silica and of the water to alumina varies considerably and in only one case approaches at all closely to simple ratios.

The formulae deduced from the molecular ratios are as follows:

(1) $[12\frac{1}{2}CaAl_2Si_4O_{12}.6H_2O + 7Na_2Al_2Si_4O_{12}.6H_2O] + 4H_2O$

(2) [15 „ + 4 „] $+ 1\frac{1}{2}SiO_2 + 9H_2O$

(3) [9 „ +10 „] $+ 3SiO_2 + 6H_2O$

(4) [15 „ + $3K_2Al_2Si_4O_{12}.6H_2O$] $+ 8SiO_2 + 12H_2O$

(5) [16 „ + 2 „] $+ 9SiO_2 + 15H_2O$

The gmelinites agree more closely than the phacolites with the usually accepted formula $(Ca,K_2,Na_2)\ Al_2Si_4O_{12}.6H_2O$, but in all the analyses, except No. 1, there is an excess, which becomes considerable in the case of the phacolites, of silica and water over that required by the formula. The similar behaviour of nepheline and analcite in this respect has been discussed more especially by H. W. Foote and W. M. Bradley.[1] They regard the excess of silica in the case of nepheline, and of silica and water in the case of analcite, as present in solid solution and prefer to leave open the question as to what form the excess takes. In the case of nepheline, W. T. Schaller[2] and N. L. Bowen[3] suggest that the excess takes the form of the albite molecule $NaAlSi_3O_8$. Previously, in order to explain the excess in the case of analcite, F. W. Clarke and

[1] H. W. Foote and W. M. Bradley, Amer. Journ. Sci., 1911, vol. xxxi, p. 25, and 1912, vol. xxxiii, pp. 433 and 439.

[2] W. T. Schaller, Journ. Washington Acad. Sci., 1911, vol. i, p. 109.

[3] N. L. Bowen, Amer. Journ. Sci., 1912, vol. xxxiii, p. 49.

G. Steiger[1] had made the similar proposal that the formula should be written $NaAlX.H_2O$, in which X represents $nSiO_4 + mSi_3O_8$.

In the present case a somewhat similar explanation may be doubtfully advanced to account for the excess of silica, viz. that in the atomic arrangement in the crystals the calc-felspar grouping $CaAl_2Si_2O_8$ may form a layer and be partially replaceable not only by the nepheline molecule $Na_2Al_2Si_2O_8$, but also to some extent by the alkali-felspar grouping $(Na,K)AlSi_3O_8$. This might be equivalent to adopting for chabazite the formula $(Ca,Na_2,K_2)Al_2Si_2O_8.2H_2SiO_3.4H_2O$, in which the first part can be partially replaced by $(K,Na)AlSi_3O_8$. This formula is similar to the $Na_2Al_2Si_2O_8.2H_2SiO_3$ once proposed by Doelter[2] for analcite, which was dismissed perhaps somewhat too readily by Clarke and Steiger[3] on the ground that there was little splitting off of silica on boiling with sodium carbonate solution.

D. *Position of Gmelinite.*

The reasons for supposing that gmelinite is a variety of chabazite, and not a distinct species, are of the following character:

1. The values of the axial ratios, whether calculated from the phacolite or the gmelinite type of crystal, are the same within the limits of errors of observation.

2. Gmelinite is evidently rhombohedral and not hexagonal in symmetry, because the twin individuals always occur in sets of three.

3. All types of crystals may be met with between, on the one hand, the simple primitive rhombohedron and, on the other hand, the complexly-twinned pseudo-hexagonal crystals.

4. The chemical composition of gmelinite does not differ materially from that of any other type of chabazite; the principle of isomorphism will account for any difference there may be.

The only contrary argument, which was assumed to be conclusive by Rose and later writers, consists in the difference in cleavage. Too much stress, however, should not be laid upon this. If the gmelinite type arises, as would appear to be the case, from a very intimate oscillatory twinning of the forms r $(10\bar{1}1)$ and e $(01\bar{1}2)$, no surprise need be felt because the cleavage parallel to the primitive rhombohedron is no longer observable, or because the prism-cleavage has become more conspicuous.

[1] F. W. Clarke and G. Steiger, Amer. Journ. Sci., 1899, vol. viii, p. 251.
[2] C. Doelter, Neues Jahrb. Min., 1890, vol. i, p. 133.
[3] F. W. Clarke and G. Steiger, loc. cit.

E. *Pseudomorphs and Alteration Products.*

Among the specimens collected from the bottom flow in the quarry on the south side of White Head are some that exhibited steeply-pyramidal and irregularly-shaped masses which have evidently resulted from the epimorphic coating of other crystals or irregular fragments that had subsequently disappeared. The coat consists in both instances of a thin layer of massive chabazite, which both inside and outside is covered with a dense mass of minute trapezohedra of analcite interwoven with thin, slender needles of natrolite. In at least one case of the pyramidal-shaped mass the interior is completely filled up by analcite and natrolite. The shape of these tapering pseudomorphs suggests that they have originated from the formation of epimorphs on steep scalenohedra of calcite, a suggestion supported by the fact that such crystals have been found in massive chabazite on specimens from Craigahulliar (p. 302). The polar distance from *c* and azimuth from the zone [*cf*] in the case of the form Ω_1 (6. 5. $\bar{1}\bar{1}$. 1) characterizing the Craigahulliar crystals are respectively 83° 56′ and 27° 0′, and the angles over the top and of the basal section are therefore 12° 8′ and 54° 0′. Anything approaching accuracy in the measurement of the pseudomorphs with a contact-goniometer is quite out of the question owing to the roughness of the surfaces. The angle over the top appears to be about 15°; where the pseudomorph was fractured the section is distinct and the measured angle, 55°, is probably fairly accurate. The irregularly-shaped masses, on the other hand, have no doubt at one time coated fragments of basalt, and, in fact, in some instances the basalt kernel is still in position.

The specimens from the same locality which show the small globules of calcite (p. 304) display in addition spiky growths, about 2–5 mm. in length and about 1–2 mm. in diameter at the base, tapering upwards. On examination, these growths are found to be in two parts, viz. a core and a covering sheath. The latter, which is white, is composed of chabazite enclosing a little natrolite, and on it are perched the usual brilliant trapezohedra of analcite. The core, which is stained on the surface a pale greenish-yellow, consists of massive analcite enclosing a heterogeneous mass of minute needles of natrolite.

On many of the specimens from the bottom flow on the south side of White Head in 1908 the layer of chabazite lining the cavities in the basalt betrays obvious signs of corrosion, being partially fretted and eaten away. The first product of the alteration appears to be analcite, which is found in comparatively large crystals (up to about 2 mm.

Photo by R. Welsh.

WHITE HEAD FROM THE NORTH SHOWING THE LARGE QUARRY.

G. F. H. Smith, F. N. Ashcroft, and G. T. Prior: Chabazite from Co. Antrim.

Photo by R. Welsh.

QUARRY ON THE NORTH SIDE OF WHITE HEAD.

C = *Chalk.* *B* = *Basalt.*

Stanley Wilson, sc.

G. F. H. Smith, F. N. Ashcroft, and G. T. Prior: Chabazite from Co. Antrim.

Photo by R. Welch.

DISUSED QUARRY ON THE SOUTH SIDE OF WHITE HEAD.

The arrows indicate approximately the points in the lowest flow from which specimens were obtained

Stereograph.

G. F. H. Smith, F. N. Ashcroft, and G. T. Prior: Chabazite from Co. Antrim.

Swaingravure. *Photo by R. Welsh.*

CUTTING LEADING TO THE QUARRY ON CRAIGAHULLIAR.

Swaingravure. *Photo by R. Welsh.*

"KILLYFLUGH" QUARRY NEAR BALLYMENA.

G. F. H. Smith, F. N. Ashcroft, and G. T. Prior: Chabazite from Co. Antrim.

across). The second product is natrolite, which occurs in the usual prismatic crystals, sometimes feathery at the free ends (cf. p. 302); it is always accompanied by analcite in extremely tiny crystals. The chabazite seems to have been originally of the gmelinite habit.

IV. Associated Minerals.

The minerals associated with chabazite in the cavities and seams in the amygdaloidal basalt are analcite and natrolite in considerable amount, and to a far lesser extent calcite and mesolite.

(*a*) *Analcite.*

This mineral occurs in typical trapezohedral crystals *n* (211), which are usually transparent and often water-clear, without trace of colour, and small in size, rarely exceeding a millimetre across, and often quite minute. The crystals exhibit the usual distortions, the faces giving on the goniometer multiple images of the signal, and under the polarizing microscope the crystals showing anomalous double refraction. Discrimination between it and chabazite in small fragments under the microscope is not easy, since the mean refractive indices are nearly the same and there is little difference in the amount of double refraction.

All the localities yielded specimens of analcite. On one interesting specimen from the quarry on the south side of White Head the mineral has the form of extremely thin, hexagonal, colourless plates penetrated by needles of natrolite. Measurement by revolving the spider-line of the upper nicol showed that the angles of the hexagon are not all equal, and the plates are evidently flattened parallel to one of the faces of the form *n* (211). On another specimen from the same locality, crystals of analcite are piled on one another to form a columnar mass. The specimens from the old land-surface in the quarry on the north side yield mainly analcite. Sometimes there are two crops, isolated crystals lying on a continuous carpet of tiny crystals. At Killyflugh the mineral occurs as a crust of tiny crystals of such perfect transparency that their colour is apparently that of the background. A few crystals of analcite were found on some of the specimens from Craigahulliar.

(*b*) *Natrolite and Mesolite.*

Natrolite was found in considerable quantity at the quarries on both sides of White Head, but at neither of the other two localities. It occurred in the usual prismatic crystals, with the forms *m* (110) and *o* (111). Three types of aggregation were observed.

1. In globular masses. The structure at the centre is almost massive, the component crystals being pressed tightly together, but farther out the several crystals had room for independent growth; the larger the globule the thicker are the component needles.

2. In distinct crystals, springing out from analcite or decomposed chabazite.

3. Often in the case of both the previous modes of occurrence the condition under which crystallization has taken place has changed from the metastable to the labile, and we find the comparatively stout prismatic crystals terminating in a number of feathery branches.

Delicate hair-like crystals of mesolite accompanied phacolite at the Killyflugh quarry; they are almost optically isotropic.

(*c*) *Calcite.*

This mineral was found in some abundance on specimens from Craigahulliar, and to a more limited extent on those from the quarries on either side of White Head; it was not observed on specimens from Killyflugh.

On the specimens from Craigahulliar two kinds of crystals were seen. The first characterizes the crystal embedded in massive chabazite. The shape is tapering, and is due to the prominent development of a steep scalenohedron. A partially developed crystal was successfully removed from the matrix, and on goniometric examination of it the faces were found severally to lie in zones connecting the cleavage faces. The most trustworthy value of the distance from the pole *e* ($01\bar{1}2$) as determined from the readings was 83° 4′. The scalenohedron is therefore Ω_1 ($6.\ 5.\ \bar{1}\bar{1}.\ 1$), the corresponding calculated value of which is 83° 14′. A reading, giving the value 88° 15′ as the distance from *e* ($01\bar{1}2$), was obtained for a small face lying on an edge with a small cleavage face at the top; the corresponding face has the indices ($22.\ 21.\ \bar{4}3.\ 1$), the calculated value for which is 88° 15½′. A number of small crystals, under a millimetre in length, of the type illustrated in fig. 11, occur perched on the twinned crystals of phacolite. The faces of the form *f* ($02\bar{2}1$), which are smooth and gave good reflections, were used for

setting up the crystal for measurement on the three-circle goniometer. The mean value for the distance *cf*, viz. 63° 8′, agrees closely with the accepted value, 63° 7′. The form *M* (40$\bar{4}$1) was determined from the fact that the faces lay in the zone [*cf*] on the side of the axis remote from *f*, and the observed values for the distance *cM* were 75° 46′, 75° 50′, 75° 52′, the corresponding calculated value being 75° 47′; the faces being small gave only faint reflections. The faces of the form Ω_1 (6. 5. $\bar{1}\bar{1}$. 1) are dull and give indistinct reflections; nevertheless, the observed values for the distance and azimuth (the azimuth of *f* being taken as zero), viz. 83° 39′, 26° 58′; 83° 3′, 26° 42′, are in satisfactory agreement with the corresponding calculated values 83° 56′,

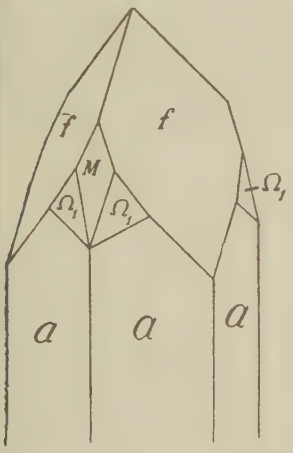

Fig. 11.—Calcite from Craigahulliar.

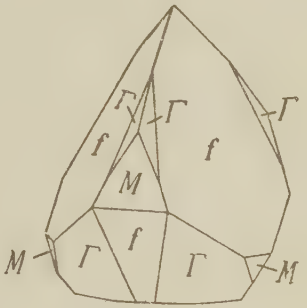

Fig. 12.—Calcite from White Head.

27° 0′. The prism-faces are very dull, and give reflections diffused in the zone with Ω_1. Measurements were obtained which pointed to the presence of minute faces of the form (22. 21. $\bar{4}\bar{3}$. 1), the observed and calculated values of the distance and azimuth being respectively 88° 5′, 28° 59′; 88° 26′, 29° 14′.

Crystals (fig. 12) similar to the latter type, but still smaller in size, were found on a few specimens from the quarry on the north side of White Head. One crystal was removed for determination of the forms present, which proved to be *f* (0$\bar{2}$21), *M* (40$\bar{4}$1), and Γ (35$\bar{8}$4). As before, the faces *f* were used for setting up the crystal. The observed and calculated values of the distances for the three forms respectively

are f 63° 8′, 63° 7′; M 76° 5′, 75° 47′; Γ 59° 59′, 59° 55′. The corresponding values of the azimuth of Γ, that of f being taken as zero, are 21° 42′, 21° 47′. Very much larger crystals, 15–20 mm. in length, of similar form, were found occurring alone.

On some of the specimens, collected from the bottom flow in the quarry on the south side, tiny, white balls, about 0·7 mm. in diameter, of spherulitic calcite, are sprinkled sparingly on a carpet of needle-like crystals of natrolite closely interwoven with tiny trapezohedra of analcite. A few needles of natrolite with most minute flakes of analcite spring out from the spherulites.

V. Relation between Chabazite, Analcite, and Natrolite.

That a very close relationship subsists between the three zeolitic minerals, chabazite, analcite, and natrolite, as regards not only their chemical composition, but also their physical properties, is shown below.

Natrolite.—$Al_2O_3.Na_2O.3SiO_2.2H_2O$.

Hardness 5. Specific gravity 2·3. Refractivity 1·483.

Orthorhombic; $a : b : c = 0{\cdot}9785 : 1 : 0.3536$.

We may, however, transform the axes so that the poles (110), (1$\bar{1}$0), (001), (401) become respectively (100), (001), (010), (111), and express the fundamental constants in the following form:

$$a : b : c = 0{\cdot}9893 : 1 : 0.9893; \ \beta = 91° 14\tfrac{1}{2}'.$$

Analcite.—$Al_2O_3.Na_2O.4SiO_2.2H_2O$.

Hardness 5. Specific gravity 2·3. Refractivity 1·487. Cubic.

Chabazite.—$Al_2O_3.Na_2O.4SiO_2.6H_2O$, to take the simplest formula to which the composition approximates.

Hardness 5. Specific gravity 2·1. Refractivity 1·485.

Rhombohedral; $a : c = 1 : 1{\cdot}0860$.

The fundamental constants may, however, be expressed in the form

$$a : b : c = 1 : 1 : 1; \ \alpha = \beta = \gamma = 94° 24'.$$

In all three instances, therefore, the crystalline arrangement is actually or approximately cubic.

The Natrolite occurrence near Kinbane (White Head), County Antrim.

By F. N. Ashcroft, M.A., F.G.S.

[Read November 11, 1913.]

IT is impossible to determine when this natrolite occurrence was first discovered, but it has been known at any rate locally for many years, and specimens of the mineral may frequently be seen in collections,[1] where, however, they are usually labelled as from the Giant's Causeway.[2] This error in localization is largely accounted for by the fact that the guides at the Giant's Causeway regularly offer specimens of the mineral for sale to visitors, together with other so-called Giant's Causeway minerals, fossils, and flint implements.

When visiting the Giant's Causeway in June, 1909, several good specimens of this natrolite were offered to me, and I learnt that they had been obtained from an occurrence on the cliffs a little eastward of Kinbane, some nine miles to the east of the Causeway proper and about two miles westward of Ballycastle. In the following May I visited this locality in company with one of the Causeway guides, and again in July, 1912, with Mr. Arthur Russell.

The locality is situated in the townland of Cregganboy on the face of the cliffs, which there rise to a height of 250–300 feet from the sea, at a point about 300 yards E.N.E. of Cregganboy farm and just over

[1] Two fine specimens are exhibited in the British Museum (Natural History) which were bequeathed to the Museum in 1907 by Miss Caroline Birley, who had obtained them a few years previously from one of the Causeway guides.

[2] Only in very few instances is it possible to locate with any accuracy the place of origin of minerals described by early mineralogists as from the Giant's Causeway. Not only was the name used in a very wide and vague sense, but in many cases the sole evidence as to locality is the label of the well-known Irish collector and dealer, Patrick Doran, whose localities unfortunately were frequently regrettably inaccurate. As far as the author is aware, there is no well-marked natrolite occurrence on the cliffs in the vicinity of the Causeway, i.e. those lying between Bushfoot Strand and White Park Bay, where fine specimens of the mineral, similar in quality and mode of occurrence to those here described, have been obtained in any quantity; though seams similar to those found near Kinbane are visible at the foot of Plaiskin Head, and probably elsewhere also.

800 yards S.E. by S.S.E. of Kinbane Castle, a small ruined castle on Kinbane.

It can be reached either by boat from Ballycastle, or by descending a small steep gap in the cliffs some 300 yards eastward of the occurrence, and climbing first along the base of the cliffs and then over a great mass of fallen boulders,[2] and again along the cliff. But in stormy weather or if there is any ground swell, neither the traverse along the base of the cliffs nor a landing is possible. Access from the west is stopped by two caves into which the sea enters. The actual spot, which is about 50–60 feet or so above sea-level, is easily identified, for the guides from the Causeway have driven several small levels into the face of the cliff for the express purpose of obtaining specimens of the 'needlestone'.

The rock in which these excavations have been made is a bed of decomposed basalt varying considerably in hardness and colour—from greyish-black to reddish-brown. This bed is seamed with irregular veins filled with natrolite (and its associates), which frequently widen out into irregular angular cavities lined with fine radiating aggregates of the mineral, often in association with calcite and sometimes with analcite.

Similar white seams are also visible on the cliff face a little farther eastward, just beyond the fall of rock, but the steep face of the cliff offers no opportunity for collecting.

The natrolite forms finely fibrous to acicular radiating masses terminating when freely developed in thick clusters of fine needle-like crystals, which reach 1—1·5 cm. in length, but which rarely exceed

[1] Kinbane or Kenbane means in Irish 'White Head', and the form Kinbane Head sometimes used is incorrect. On the six-inch Ordnance Survey map (Sheet No. 4, 2nd ed., 1906) this promontory is marked 'Kinbane or White Head'. The exact spot where the natrolite is found lies on the cliff face due north of the letter 'A' in Carmoon on this map. This promontory is not to be confused with that of White Head at the entrance to Belfast Lough.

[2] This fall of rock, which completely blocks the entrance of a cave into which the sea formerly entered, occurred about the year 1895 as the result of the diversion of a small stream from a quarry known as Dr. Woodside's quarry at the top of the cliff. In this quarry the basalt, though much fissured, is hard and compact. It is traversed by several more or less horizontal bands which are amygdaloidal in character. These bands, which do not appear to exceed 1–1½ ft. in thickness, are very sharply defined. They are not continuous across the quarry face, thinning out at one or both ends. The cavities in them are quite small and usually completely filled with zeolitic minerals, but in some cavities comparatively large, transparent, and well-developed crystals of analcite are to be found. In the solid basalt one cavity was observed showing traces of weathered gyrolite and faroelite, and one containing analcite.

1 mm. in thickness. As a rule, the mineral is colourless or pure white, but not infrequently it shows portions of a reddish-brown tint.

Of the associated minerals, calcite is by far the most frequent. It occurs in two generations, one earlier and the other later than the natrolite; in the latter case frequently enclosing numbers of otherwise freely developed natrolite needles. The crystals vary considerably in habit. On one specimen in the author's collection the 'needlestone' supports small, dull rhombohedra of the form $f(11\bar{1}) = -2R$.

Two generations of analcite also appear to be present, one earlier and one later than the natrolite. The crystals are of the usual form n (211) and are generally quite small and colourless, though crystals of about 1 cm. in diameter have been noted. The latter appear to be in contact with the matrix and to belong to a generation deposited before the natrolite, but their place in the order of deposition is not very clearly defined.

Examination of the 'needlestone' obtained proved it to be a typical natrolite. The crystals are bounded by the nearly square prism m (110) and terminated by the low pyramid o (111). In polarized light they give straight extinction and are optically positive in the direction of their length. By immersion in xylol the refractive index for vibrations parallel to the length of the needles was found to be about 1·487 in white light.

The following analysis was made on pure, colourless and freely developed needles which are easily detached from the surface of the specimens. They were freed from dust and foreign material by shaking over a pinhole sieve and by washing with water, and on examination under a lens showed no signs of adherent calcite or analcite. The solid central portions of the radiating masses were rejected as likely to be impure and variable in composition.

	Percentage composition.	Molecular ratios.		Calculated for $Na_2O.Al_2O_3.3SiO_2.2H_2O$.
SiO_2	47·22	0·7870	3·07	47·36
Al_2O_3	27·21[1]	0·2668	1·04	26·86
CaO	nil	—	—	—
Na_2O	15·86	0·2564	1·00	16·32
K_2O	0·06			—
H_2O	9·70	0·5388	2·06	9·46
	100·05			100·00

[1] Inclusive of a trace of Fe_2O_3.

There is little doubt that the occurrence here described is the same as that recorded by J. S. Hyland[1] in his paper entitled 'On the Mesolite (Galacite) of Kenbane Head, Co. Antrim', though he gives no detailed description of the occurrence, which is dismissed in the following few words: 'Along the cliff near Kenbane Head about two miles west of Ballycastle, Co. Antrim, the decomposed basalt is seamed with veins of white needle-like zeolite . . .' His analysis of the needlestone, however, showed the presence of 2·59 per cent. of lime, which, as he was satisfied as to the purity and homogeneity of the material used, required some explanation. He considered the mineral analysed as an isomorphous mixture of natrolite and scolecite in the ratio of 9 : 2 and classed it as a 'mesolite',[2] to which category he refers all lime-containing natrolite.

In conclusion I desire to express my thanks to Mr. L. J. Spencer and Lieut. W. Campbell Smith, of the British Museum (Natural History), for their kind assistance.

[1] J. S. Hyland, Sci. Proc. Roy. Dublin Soc., 1890, new series, vol. vi, pp. 411–419.
[2] Compare R. Görgey, Min. Petr. Mitt., 1909, vol. xxviii, pp. 77–106.

Proustite from Cobalt, Ontario.

By Arthur L. Parsons,

Assistant-Professor of Mineralogy, University of Toronto.

[Read June 15, 1915.]

DURING the summer of 1913 the Royal Ontario Museum of Mineralogy secured a number of samples of ruby-silver from the collection of a deceased mining engineer who had been employed in the Cobalt district. Judging from their association it is presumed that they were obtained from the O'Brien mine. The crystals for the most part are less than two millimeters in length and very few exceed a millimeter in diameter. They are light ruby-red in colour and exceedingly brilliant, and casual inspection suggested that they were proustite. As this mineral had not been described from the Cobalt region, it seemed desirable to confirm this supposition by chemical analysis and crystallographic measurement.

Chemical Examination.

The material for analysis was obtained by floating the crystals from a large quantity of fine material which had broken away from the larger specimens. In this operation it was found that certain impurities accompanied the proustite, so that the final separation was made by means of a brush and lens. It was observed that many of the crystals still had a slight trace of what appeared to be smaltite attached to one end, but with the material at hand it did not appear feasible to remove the last trace of impurity.

It was also observed that in some instances the crystals were somewhat dark for proustite and in most cases these were discarded, but the small amount of antimony found in the analysis would indicate that a little pyrargyrite is mingled with the proustite.

The analysis was made by Mr. H. V. Ellsworth, M.A., Fellow in Mineralogy, with the following results:

Ag	64·12
As	15·90
S	19·28
Sb	0·08
Fe	0·25
Co (including trace of Ni)	0·12
Insoluble in HNO_3	0·38
	100·13

The percentages for silver, arsenic, sulphur, and iron are the averages of two determinations for each. The determinations for antimony and insoluble were made only once, while the cobalt-nickel determination was obtained by combining the cobalt-nickel contents of two analyses.

If we assume that the iron is combined with sulphur in the form of pyrite and the cobalt with arsenic in the form of smaltite, the recalculation gives a nearly pure proustite with a small excess of arsenic as follows:

	Percentages.	Atomic ratios.	Pyrite.	Smaltite.	Pyrargyrite.	Proustite.	Arsenic.
Ag	64·12	·0·595	—	—	0·021	0·574	—
As	15·90	0·212	—	0·004	—	0·191	0·017
S	19·28	0·602	0·008	—	0·021	0·573	—
Sb	0·08	0·007	—	—	0·007	—	—
Fe	0·25	0·004	0·004	—	—	—	—
Co	0·12	0·002	—	0·002	—	—	—

Converting these atomic ratios into percentages we get:

Proustite	94·62
Pyrargyrite	3·77
Smaltite	0·04
Pyrite	0·05
Arsenic	1·27
Insoluble	0·38
	100·13

Besides adding proustite to the already large number of minerals from Cobalt, this analysis is of interest in that it suggests the presence of native arsenic from this region. Up to the present time the latter has not been found at Cobalt, though it is a mineral which is to be expected.

Crystallographic Examination.

Inspection with a pocket-lens showed that the crystals were of two types, one characterized by a rhombohedron and a prominent prism (fig. 1), while the other showed in addition to the above certain scalenohedral faces (fig. 2). In no case was a doubly terminated crystal found.

For purposes of calculation five crystals were carefully measured on a Goldschmidt two-circle goniometer, while a sixth crystal was examined, but without success, for new forms. The table given below shows the forms found and the number of faces of each form found on each crystal.

Forms.	Crystals.				
	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
a (11$\bar{2}$0)	6	5	6	6	6
b (10$\bar{1}$0)	3	1	1	4	5
r (10$\bar{1}$1)	—	—	1	1	—
e (01$\bar{1}$2)	3	3	3	3	3
s (02$\bar{2}$1)	—	3	—	—	3
Γ (07$\bar{7}$2)	—	—	—	—	1
v (21$\bar{3}$1)	—	5	6	4	6
y_1 (13.7.2$\bar{0}$.6)	—	?	5	—	—

The form y_1 (13.7.2$\bar{0}$.6) is new for proustite and was identified with certainty on one crystal (No. 3) only. The signal is a distinct cross in a path of the light-figure extending from v (21$\bar{3}$1). The observed and calculated positions for this form are:

	Observed.					Average.	Calculated.[1]
ϕ	10° 04′	9° 51′	9° 35′	10° 02′	9° 39′	9° 50′	9° 50′
ρ	69° 29′	69° 42′	69° 50′	69° 29′	69° 59′	69° 42′	69° 48′

In crystal No. 2 a series of signals in the light-paths extending from v (21$\bar{3}$1) were observed, and some of the signals lie close to the position for the new form y_1, but they were not sufficiently definite for calculation and showed little agreement among the readings for the various faces on the same crystal.

The form e (01$\bar{1}$2) affords the best defined of the terminal faces, and usually gives a distinct signal which agrees well with the calculated position for this form. Observed ρ 25° 0′, 24° 57′, 24° 59′ (calculated

[1] Calculated from the angle $cr = 42° 51′$ of Miller (1852); corresponding with the axial ratio $a : c = 1 : 0{\cdot}8034$.

24° 53′). The greatest variation from the calculated position is in crystal No. 3, where the angle ρ is uniformly about 7′ too great.

The form r (10$\bar{1}$1), which was found on two crystals, gives readings for ρ which are slightly lower than the calculated value. Observed ρ 42° 40′ and 42° 46′ (calculated 42° 51′).

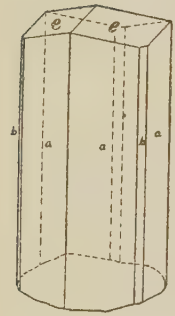

Fig. 1.

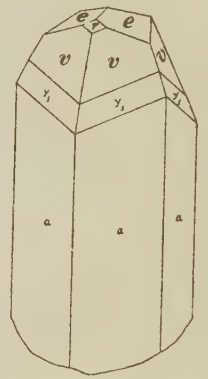

Fig. 2.

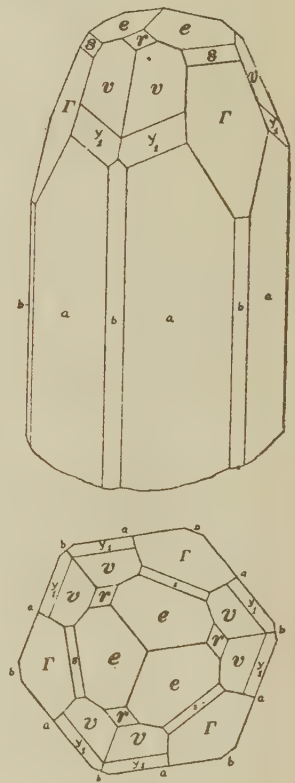

Fig. 3.

Proustite from Cobalt, Ontario.

The form s (02$\bar{2}$1) is apparently an etched surface. The faces are well defined, but give hazy signals which indicate positions between $\frac{19}{10}$ and $\frac{21}{10}$. The mean of these values is taken as the best value for the form.

The form Γ (07$\bar{7}$2) is found as a single face on crystal No. 5. The face is fair, but the signal is hazy and lies between $-\frac{7}{2}$ and -4, being nearer $-\frac{7}{2}$. Exact measurements could not be made, and the form must be considered doubtful.

The form v (2131) was found on four crystals and may be considered the dominant scalenohedral face. The faces are well defined, but the signals are characterized by pronounced light-paths, which in crystal No. 3 extended to the new form y_1 (13.7.$\bar{2}0$.6).

	Observed.				Calculated.
ϕ	10° 38′	10° 56′	11° 03′	10° 50′	10° 53′
ρ	67° 45′	68° 02′	67° 55′	67° 47′	67° 50′

The prism a (11$\bar{2}$0) was found on all the crystals. The faces are well developed, but have a slight etching which tends to displace the signal from the calculated position. In some cases the signal shows a U-shaped curve which might be considered indicative of hemimorphic development if found with a greater degree of regularity. The prism b (10$\bar{1}$0) was also found on all the crystals, and is usually shown as a slight truncation of the prism a.

The accompanying text-figures illustrate the two types of crystals: fig. 1 representing crystal No. 1; fig. 2 representing crystal No. 3; but showing the new form y_1 with six faces instead of five as actually observed; and fig. 3 representing the combination of all the observed forms in idealized development.

The average value obtained for the axial ratio by taking all the measured angles is $a : c = 1 : 0{\cdot}8015$, but rejecting the measurements from the form y_1 (13.7.$\bar{2}0$.6) the average is $1 : 0{\cdot}8025$. The average of all values for crystal No. 1 is $1 : 0{\cdot}8027$. These are slightly lower than the value ($a : c = 1 : 0{\cdot}8039$) given by Miers in 1888.

Crystallographic relations of allied substances traced by means of the law of valency-volumes.

By W. Barlow, F.R.S.

[Read November 2, 1915.]

A WORD of explanation as to the nature of valency-volumes: The existence of the law of valency-volumes involves the conclusion that each chemical atom in a crystal has its own special domain throughout which its influence is predominant as compared with that of any other atom. According to this conception the entire space occupied by the crystal can be regarded as portioned out among its constituent atoms, each atom having a cell allotted to it the boundaries of which consist of points at which the influence of some one or more neighbouring atoms is equal to that of the selected atom; thus no interstices are left between the cells. For the purpose of the present communication, the question of the shapes of these domains does not arise; the facts to which I am about to call attention are connected with the relative volumes thus definitely appropriated by the several atoms in a given compound, and not with the forms of the atomic domains. Evidence will, however, appear that as we pass from one compound to another partially similar to it, the shapes of the corresponding domains present a certain constancy of pattern, while differing in absolute magnitude.

The investigation of the structure of crystals by means of X-rays has afforded direct evidence of the soundness of the contention that the atom preserves its individuality after chemical combination with other atoms. This new method of analysis has indeed revealed the nature of the pattern of the point-system formed by atomic centres of the same kind in some simple cases; and it is important to notice that, when isomorphous substances of similar atomic composition are compared, close similarity of the pattern formed by the atomic centres of a given kind common to the compared bodies is associated with a marked difference of scale, viz. of actual dimensions. Thus the distances separating the sulphur atoms in potassium sulphate will not be the

same as those separating these atoms in caesium sulphate; corresponding dimensions of the two bodies, as is easily perceived, will be very approximately in the ratio of the cube roots of the respective molecular volumes. It is suggested that the same difference of scale characterizes the two systems of cells respectively produced by appropriate partitioning of the two isomorphous crystals into atomic domains as above indicated. And, if this is the case, these systems of cells will be extremely similar in form, indicating similar conditions of equilibrium, and the dimensions of an atomic domain of the one crystal will respectively bear to the corresponding dimensions of a similar domain of the other crystal approximately the ratio of the cube roots of the two molecular volumes.

With regard to the law of valency-volumes on which the work recorded in this communication is based: Experimental facts previously published have led to the conclusion that a certain relation subsists between the amounts of space appropriated by the several atoms in a given compound; the volumes of the cellular domains allotted as above described are found to be very approximately in the ratio of the integers which respectively express the fundamental chemical valencies of their contained atoms. In the cases of atoms which under different conditions possess different chemical valencies, a general study of the chemical behaviour and isomorphous relations of the atom is found to lead to the selection of one of its valency values as fundamental and giving the valency-volume for all its compounds of whatever nature, e. g. sulphur is taken to be fundamentally divalent, so that its atom appropriates a space equivalent to two units of valency-volume in all cases.

It is a familiar fact that in a strictly isomorphous series of substances of similar atomic composition, the atoms, the interchange of which produces one term from another, are of the same chemical valency; this is in agreement with the above law and the simple conception connected with it, taken in conjunction with the partial identity of composition pervading such a series. For if the same proportion of the total molecular volume is allotted to the common radicle or atom, as the case may be, in each of the two compared isomorphous assemblages, the two remaining volumes, which are respectively allotted to the interchangeable atoms or radicles, will also bear the same proportion to the respective molecular volumes; consequently the atoms or radicles respectively appropriating these remaining volumes will, in agreement with the above law, present the same fundamental valency or sum of fundamental valencies.

The dimensional similarities of crystals of allied substances to which I shall presently direct your attention, can be traced by comparing the ordinary axial ratios, but a recognition of these resemblances is much facilitated by the use of equivalence-parameters. These are obtained from the recorded axial ratios, or from some slight modification of them, by expressing the ratios in terms of a volume unit instead of making the parameter y unity. The crystal of each substance has its own volume unit, which is the space occupied in it by a monovalent atom, half that taken up by a divalent atom or one-third of that assigned to a trivalent atom, &c.; the alternative unit volumes thus reached will, in obedience to the law of valency-volumes, be practically identical in the same compound. The equivalence-parameters x, y, z, which correspond respectively to a, b, c or to three derivatives of a, b, c selected as hereafter appears, present the same ratios as the indices from which they are derived, and they are the three dimensions of a parallelepiped having the volume of the molecular unit of the given crystal expressed in terms of the unit volume assigned in it to a monovalent atom. Thus W, the total of the fundamental valencies of the atoms composing the molecular unit, gives the volume of the parallelepiped of which the edges are x, y, z respectively in terms of the unit volume referred to. This definition takes for granted the existence of the valency-volume law. The equivalence-parameters are calculated by means of formulae analogous to those employed for obtaining the 'topic axial ratios'. Thus

$$x = \sqrt[3]{\frac{a^2 W}{c \sin A \sin \beta \sin \gamma}}; \quad y = x/a; \quad z = cy.$$

The relation between the x, y, z and the a, b, c of a crystal will clearly appear from the succeeding examples, and the advantages of the former notation over the latter in the cases cited will be sufficiently obvious.

The ordinary parameters derived for a given crystal from the directions of the principal faces are often tacitly assumed to express the ratios between the minimum translations of the crystal-structure. There is, however, no adequate evidence warranting this as a general proposition, and indeed some very familiar facts are opposed to any such assumption. A case in point is furnished by calcite. In consequence of the great variety of forms presented by this mineral, it would be virtually impossible, but for the existence of the very perfect cleavage, to select with certainty the set of rhombohedral faces which are to be regarded as fundamental. Such a condition of things clearly indicates that the

determination which of the structural planes of like points shall be face-directions does not necessarily depend on the nature of the unit of the atom arrangement; there is no reason to suppose that the disposition of the atoms differs in the different forms of calcite, and indeed the facts that the dimensional relations of all the forms are strictly compatible and the cleavages identical quite negative such a supposition. Fedorov's admirable system for obtaining uniformity in the method of measuring crystals has no application to the discovery of the fundamental space-lattice of the crystal-structure; for while the recorded parameters are data with which this space-lattice, which is based on the minimum translations, must be consistent, they do not give us its form. In simple cases we must look to the X-ray method of investigation to ascertain this if it is not deducible from the cleavages.

I make these remarks in connexion with the modification of the recorded indices which is resorted to in most of the examples that follow. My contention is that the modifications made, the multiplication of one or sometimes two of the parameters by some small integer, need no further justification. I may mention that in nearly every case I feel confident that no other simple modification than that suggested will lead to such remarkably close agreement between the equivalence-parameters of the compared crystals. It is not suggested that the modified parameters necessarily give the relative dimensions of the fundamental space-lattice; the object of the modification is to find for the crystal of the one compound a set of parameters compatible with the parameters of the crystal of the compound with which it is to be compared. The degree of correspondence reached is taken to indicate whether or no this object has been attained.

The theory finally reached by Sohncke that a crystal can be regarded as a combinatior of regular point-systems has received experimental support from the X-ray method of investigation, for this reveals an arrangement of the atomic centres to form a system of congruent interpenetrated space-lattices. It seems therefore unquestionable that isomorphous and other morphotropic resemblances between the crystals of allied compounds are traceable to some close approximation of pattern of the respective point-systems formed by the atomic centres. The X-ray results, as already remarked, do not indicate any equality of corresponding actual dimensions; comparable distances in the related crystals may be expected to bear approximately the ratio of the cube roots of the respective unit volumes.

An examination of the instances of atomic arrangement revealed by the application of X-rays shows that in some directions the centres of single atoms of the molecule and in others the centres of the atoms associated to form chemical radicles are together found in planes or strata equally spaced throughout the crystal and not containing other atomic centres. This naturally suggests that the cellular domains of the atoms thus distinguished form continuous or discontinuous tracts or strata also disposed at equal distances. Now, in testing the truth of the law by reference to the recorded axial ratios of related substances, it is found that in addition to the above simple conception regarding the similarity of the cells of corresponding atoms of isomorphous compounds of similar atomic composition, another ancillary to it, almost equally simple, is indicated by the facts. It is well known that compounds which are closely related chemically as a consequence of the presence in their molecules of the same or similarly constituted radicles, very commonly exhibit when crystallized a pronounced morphological resemblance; a close approximation is perceived between some of their respective axial ratios. This fact suggests the application to these cases of a conception similar to that just put forward with regard to isomorphous crystals, viz. that the corresponding radicles display the same geometrical form and are similarly arranged according to the same pattern in the respective assemblages of atoms containing them; and that the partial morphological resemblance found subsisting between two such assemblages is due to the presence in them both of continuous masses of similar pattern entirely composed of the radicles, these masses taking the shape of continuous uniformly constituted strata of the same mean thickness throughout, or of columns, the pattern and mean section of which are uniform. The similarly constituted strata or columns of domains of influence of the two assemblages thus produced will exhibit the relation just attributed to the similar strata of isomorphous crystals; corresponding atomic domains taken respectively in the portions of two related crystalline assemblages of similar composition and pattern will be extremely similar in form. And if V_1, V_2 be the respective molecular volumes, W_1, W_2 the respective sums of the fundamental valencies of the constituent atoms of the two related molecules, corresponding dimensions taken respectively in the similarly constituted portions of the two assemblages will bear approximately the ratio $\sqrt[3]{\frac{V_1}{W_1}} : \sqrt[3]{\frac{V_2}{W_2}}$. When similarly constituted strata of

almost identical pattern are present, it is manifest that the axial ratios of the planes of the strata taken in the two assemblages will be approximately equal, and thus that two of the three equivalence-parameters of the one assemblage will be approximately equal to two of the other. And it follows from this that the third equivalence-parameter of the one will bear to the corresponding third equivalence-parameter of the other approximately the ratio presented by the sums of the valency-volumes, viz. $W_1 : W_2$.

The following are a number of instances of close morphological resemblance in which the relation between the axial ratios of two allied substances is found to furnish evidence of the existence of the law of valency-volumes. In each case the molecules of the bodies compared contain a like chemical radicle, either identical or of similar constitution; and the dimensional relations observed, interpreted in the light of the law, indicate a stratification of the crystal structure, in both compounds, such that uniform similar layers or strata, evenly spaced, consisting solely of the radicles referred to, can be discriminated. These layers alternate with uniform layers, which can, however, be continuous or discontinuous, also similar to one another, consisting of the remaining constituents of the crystal. The pattern of the atomic arrangement in the two sets of layers of similar constitution, one in each crystal, is argued to be the same; a similar disposition of the atoms having similar relative dimensions, as measured in a single layer, being present in both sets. When the law of valency-volumes is postulated, the effect of this resemblance is to give two of the equivalence-parameters of the one crystal approximately equal to two parameters of the other crystal, while the remaining parameters, one of each crystal, are approximately in the ratio of the sums of the fundamental valencies of the constituent atoms of the respective molecules. The closeness of the approximation to this relation is very evident in the cases given.

Ex. 1. *Cupric sulphate* (*Hydrocyanite*), $CuSO_4$.

Rhombic, $a : b : c = 0{\cdot}7968 : 1 : 0{\cdot}5650$. $W = 12$.

$x : y : z = 2{\cdot}3802 : 2{\cdot}9872 : 1{\cdot}6877$.

Magnesium sulphate monohydrate, $MgSO_4 . H_2O$.

Monoclinic, $a : b : c = 0{\cdot}9147 : 1 : 1{\cdot}7445$; $\beta = 91° 7'$. $W_1 = 16$.

$a_1 : b_1 : c_1 = 2a : c : b = 1{\cdot}8294 : 1{\cdot}7445 : 1$; $\gamma_1 = \beta = 91° 7'$.

$x_1 : y_1 : z_1 = 3{\cdot}1312 : 2{\cdot}9859 : 1{\cdot}7116$.

Calculated $x_1 = \frac{W_1}{W} x = 3{\cdot}17$.

Ex. 2. *Calcium sulphate* (*Anhydrite*), $CaSO_4$.

Rhombic, $a:b:c = 0{\cdot}8932:1:1{\cdot}0008$. $W = 12$.

Since $b = c$ nearly, $a':b':c' = 0{\cdot}8932 : \frac{1}{\sqrt{2}} : \frac{1}{\sqrt{2}} = 1{\cdot}2632:1:1$.

$x':y':z' = 2{\cdot}6753:2{\cdot}118:2{\cdot}118$.

Calcium sulphate dihydrate (*Gypsum*), $CaSO_4 . 2H_2O$.

Monoclinic, $a:b:c = 0{\cdot}6895:1:0{\cdot}4132$; $\beta = 98°\,58'$. $W_1 = 20$.

$a_1:b_1:c_1 = \frac{b}{2}:a:c = 0{\cdot}5:0{\cdot}6895:0{\cdot}4132$; $a_1 = 98°\,58'$.

$x_1:y_1 \sin a_1 : z_1 = 2{\cdot}6094:3{\cdot}5544:2{\cdot}1564$.

Calculated $y_1 \sin a = \frac{W_1}{W} y' = 3{\cdot}53$.

Ex. 3. *Calcium sulphate* (*Anhydrite*), $CaSO_4$.

Rhombic, $a:b:c = 0{\cdot}8932:1:1{\cdot}0008$. $W = 12$.

$x:y:z = 2{\cdot}1228:2{\cdot}3766:2{\cdot}3785$.

Manganese sulphate tetrahydrate, $MnSO_4 . 4H_2O$.

Monoclinic, $a:b:c = 0{\cdot}4321:1:0{\cdot}5820$; $\beta = 90°\,53'$. $W_1 = 28$.

$a_1:b_1:c_1 = \frac{2}{3}c:b:a = 0{\cdot}3880:1:0{\cdot}4321$; $\beta_1 = 90°\,53'$.

$x_1:y_1:z_1 = 2{\cdot}1368:5{\cdot}5072:2{\cdot}3796$.

Calculated $y_1 = \frac{W_1}{W} y = 5{\cdot}5454$.

Ex. 4. *Calcium sulphate* (*Anhydrite*), $CaSO_4$.

Rhombic, $a:b:c = 0{\cdot}8932:1:1{\cdot}0008$. $W = 12$.

$x:y:z = 2{\cdot}1228:2{\cdot}3766:2{\cdot}3785$.

Nickel sulphate hexahydrate, $NiSO_4 . 6H_2O$.

Tetragonal trapezohedral, $a:c = 1:1{\cdot}9119$. $W_1 = 36$.

$a':c' = a:c\sqrt{2} = 1:2{\cdot}7038$.

$a_1:b_1:c_1 = c':a':a' = 2{\cdot}7038:1:1$.

$x_1:y_1:z_1 = 6{\cdot}4085:2{\cdot}37:2{\cdot}37$.

Calculated $x_1 = \frac{W_1}{W} x = 6{\cdot}368$.

Ex. 5. *Cupric sulphate* (*Hydrocyanite*), $CuSO_4$.

Rhombic, $a:b:c = 0{\cdot}7968:1:0{\cdot}5650$. $W = 12$.

Transforming axes b and c, $a':b':c' = 0{\cdot}7968:0{\cdot}984:0{\cdot}5743$; $a' = 91°\,5'$.

$x':y':z' = 2{\cdot}3802:2{\cdot}9394:1{\cdot}7155$.

Zinc sulphate hexahydrate, $ZnSO_4 . 6H_2O$.

Monoclinic, $a:b:c = 1{\cdot}3847:1:1{\cdot}6758$; $\beta = 98°\,12'$. $W_1 = 36$.

$a_1:b_1:c_1 = 3a:c:b = 4{\cdot}1541:1{\cdot}6758:1$; $\gamma_1 = 98°\,12'$.

$x_1 \sin \gamma_1 : y_1 : z_1 = 7{\cdot}185:2{\cdot}908:1{\cdot}7352$.

Calculated $x_1 \sin \gamma_1 = \frac{W_1}{W} x' = 7{\cdot}14$.

Ex. 6. *Cupric sulphate* (*Hydrocyanite*), $CuSO_4$.

Rhombic, 0·7968 : 1 : 0·5650. $W = 12$.

Transforming axes b and c, $a' : b' : c' = 0{\cdot}7968 : 0{\cdot}984 : 0{\cdot}5743$; $\alpha' = 91°5'$.

Taking a group of three molecules as unit, $W' = 36$, and

$x'' : y'' : z'' = 3{\cdot}433 : 4{\cdot}24 : 2{\cdot}474$.

Ferric sulphate enneahydrate (*Coquimbite*), $Fe_2(SO_4)_3 . 9H_2O$.

Rhombohedral, $a : c = 1 : 1{\cdot}5613$. $W_1 = 70$.

Written in rhombic form, $a : b : c = \frac{1}{\sqrt{3}} : 1 : 1{\cdot}5613$.

$a_1 : b_1 : c_1 = c : b : a = 1{\cdot}5613 : 1 : \frac{1}{\sqrt{3}}$.

$x_1 : y_1 : z_1 = 6{\cdot}66 : 4{\cdot}266 : 2{\cdot}463$.

Calculated $x_1 = \frac{W_1}{W'} x'' = 6{\cdot}675$.

Ex. 7. *Calcium sulphate* (*Anhydrite*), $CaSO_4$.

Rhombic, $a : b : c = 0{\cdot}8932 : 1 : 1{\cdot}0008$. $W = 12$.

Transforming a and b axes, $a' : b' : c' = 0{\cdot}8729 : 1{\cdot}0236 : 1{\cdot}0008$; $\gamma' = 91°29'$.

Taking a group of three molecules as unit, $W' = 36$, and

$x'' : y'' : z'' = 2{\cdot}99 : 3{\cdot}51 : 3{\cdot}43$.

Lanthanum sulphate enneahydrate, $La_2(SO_4)_3 . 9H_2O$.

Rhombohedral, $a : c = 1 : 0{\cdot}7356$. $W_1 = 70$.

Written in rhombic form, $a : b : c = 1 : \frac{1}{\sqrt{3}} : 0{\cdot}7356$.

$a_1 : b_1 : c_1 = a : 2b : 3c = 1 : \frac{2}{\sqrt{3}} : 2{\cdot}2068$.

$x_1 : y_1 : z_1 = 3{\cdot}017 : 3{\cdot}484 : 6{\cdot}6586$.

Calculated $z_1 = \frac{W_1}{W'} z'' = 6{\cdot}67$.

Ex. 8. *Cupric sulphate* (*Hydrocyanite*), $CuSO_4$.

Rhombic, $a : b : c = 0{\cdot}7968 : 1 : 0{\cdot}5650$. $W = 12$.

Transforming axes a and b, $a' : b' : c' = 0{\cdot}8492 : 0{\cdot}9407 : 0{\cdot}5650$; $\gamma' = 94°8'$.

$x' : y' : z' = 2{\cdot}5368 : 2{\cdot}810 : 1{\cdot}6877$.

Cupric lead dihydroxy-sulphate (*Linarite*), $CuPb(OH)_2SO_4$.

Monoclinic, $a : b : c = 1{\cdot}7161 : 1 : 0{\cdot}8296$; $\beta = 102°37'$. $W_1 = 20$.

$a_1 : b_1 : c_1 = 3c : a : b = 2{\cdot}4888 : 1{\cdot}7161 : 1$; $\gamma_1 = 102°37'$.

$x_1 : y_1 \sin\gamma_1 : z_1 = 4{\cdot}1978 : 2{\cdot}8246 : 1{\cdot}6867$.

Calculated $x_1 = \frac{W_1}{W} x' = 4{\cdot}228$.

Ex. 9. *Cupric sulphate* (*Hydrocyanite*), $CuSO_4$.

Rhombic, $a:b:c = 0{\cdot}7968:1:0{\cdot}5650$. $W = 12$.

$x:y:z = 2{\cdot}3802:2{\cdot}9872:1{\cdot}6877$.

Tricupric dihydroxy-sulphate (*Stelznerite*), $CuSO_4 . 2Cu(OH)_2$.

Rhombic, $a:b:c = 0{\cdot}4971:1:0{\cdot}6881$. $W_1 = 28$.

$a_1:b_1:c_1 = c:2b:a = 0{\cdot}6881:2:0{\cdot}4971$.

$x_1:y_1:z_1 = 2{\cdot}3713:6{\cdot}8925:1{\cdot}7131$.

Calculated $y_1 = \frac{W_1}{W}y = 6{\cdot}97$.

Ex. 10. *Cupric sulphate* (*Hydrocyanite*), $CuSO_4$.

Rhombic, $a:b:c = 0{\cdot}7968:1:0{\cdot}5650$. $W = 12$.

$x:y:z = 2{\cdot}3802:2{\cdot}9872:1{\cdot}6877$.

Tetracupric trihydroxy-sulphate monohydrate (*Langite*), $CuSO_4 . 3Cu(OH)_2 . H_2O$.

Rhombic, $a:b:c = 0{\cdot}5347:1:0{\cdot}6346$. $W_1 = 40$.

$a_1:b_1:c_1 = \frac{a}{2}:\frac{b}{3}:c = 0{\cdot}2673:0{\cdot}3333:0{\cdot}6346$.

$x_1:y_1:z_1 = 2{\cdot}3820:2{\cdot}9699:5{\cdot}654$.

Calculated $z_1 = \frac{W_1}{W}z = 5{\cdot}6259$.

Ex. 11. *Lithium rubidium sulphate*, $LiRbSO_4$.

Hexagonal, $a:c = 1:1{\cdot}6472$. $\frac{1}{4}W = 12$.

Written in rhombic form, $a:b:c = \sqrt{3}:1:1{\cdot}6472$.

$x:y:z = 2{\cdot}7959:1{\cdot}6142:2{\cdot}6589$.

Potassium hydrogen sulphate + Potassium iodate, $KHSO_4 . KIO_3$.

Monoclinic, $a:b:c = 1{\cdot}9288:1:1{\cdot}0346$; $\beta = 93°\,14'$. $W_1 = 20$.

$a_1:b_1:c_1 = c:b:\frac{a}{2} = 1{\cdot}0346:1:0{\cdot}9644$; $\beta_1 = 93°\,14'$.

$x_1:y_1:z_1 = 2{\cdot}812:2{\cdot}718:2{\cdot}62$.

Calculated $y_1 = \frac{W_1}{W}y = 2{\cdot}69$.

Ex. 12. *Thallous sulphate*, Tl_2SO_4.

Rhombic, $a:b:c = 0{\cdot}5555:1:0{\cdot}7328$. $W = 12$.

$x:y:z = 1{\cdot}716:3{\cdot}089:2{\cdot}2637$.

Hydrazine sulphate, $H_2SO_4 . N_2H_4$.

$a:b:c = 0{\cdot}9012:1:0{\cdot}6040$. $W_1 = 22$.

$a_1:b_1:c_1 = b:2a:4c = 1:1{\cdot}8024:2{\cdot}4160$.

$x_1:y_1:z_1 = 1{\cdot}7159:3{\cdot}0927:4{\cdot}1456$.

Calculated $z_1 = \frac{W_1}{W}z = 4{\cdot}15$.

Ex. 13. *Potassium nitrate*, KNO_3.

Rhombic, $a : b : c = 0{\cdot}5910 : 1 : 0{\cdot}7011$. $W = 10$.

$x : y : z = 1{\cdot}708 : 2{\cdot}89 : 2{\cdot}026$.

Ammonium nitrate, NH_4NO_3.

Rhombic, $a : b : c = 0{\cdot}9092 : 1 : 1{\cdot}0553$. $W_1 = 16$.

$a_1 : b_1 : c_1 = \frac{c}{2} : a : b = 0{\cdot}5276 : 0{\cdot}9092 : 1$.

$x_1 : y_1 : z_1 = 1{\cdot}7 : 2{\cdot}9267 : 3{\cdot}219$.

Calculated $z_1 = \frac{W_1}{W} z = 3{\cdot}2416$.

Ex. 14. *Rubidium hexachloro-antimonate*, $RbSbCl_6$.

Rhombic, $a : b : c = 0{\cdot}6719 : 1 : 0{\cdot}8136$. $W = 9$.

$x : y : z = 1{\cdot}7093 : 2{\cdot}544 : 2{\cdot}0697$.

Potassium hexafluoro-arsenate hemihydrate, $KAsF_6 . \frac{1}{2} H_2O$.

Rhombic, $a : b : c = 0{\cdot}8401 : 1 : 2{\cdot}5172$. $W_1 = 11$.

$a_1 : b_1 : c_1 = a : b : \frac{c}{3} = 0{\cdot}8401 : 1 : 0{\cdot}8391$.

$x_1 : y_1 : z_1 = 2{\cdot}0993 : 2{\cdot}5 : 2{\cdot}0968$.

Calculated $x_1 = \frac{W_1}{W} x = 2{\cdot}0891$.

Attention is specially directed to the case of potassium nitrate and ammonium nitrate, because this forms an exception to the rule that compounds related as these are display isomorphism. It is suggested that in the ordinary cases, in which isomorphism is presented, the resemblance of the two crystal-structures is of the same nature as that just indicated for the two compounds referred to; that the arrangement in both is such that they can be regarded as stratified in the manner described. The isomorphism displayed is ascribed to the predominant influence of the strata composed of the important radicles; this, it is suggested, causes in both crystals planes of atom-centres which are the important planes in these strata, to be selected as face-directions, subject only to such modification as is demanded by the law of rational indices. According to this view, the structural arrangement of the remaining portions, which are unlike in the two crystals, has some considerable compatibility with that of the predominating strata, and, in consequence of this compatibility, has no influence in determining crystal face-directions beyond a slight modifying effect on the parameters.

Démonstration simple de la loi de Miller.

Par G. Cesàro,

Professeur de Cristallographie et Minéralogie à l'Université de Liége.

[Read January 18, 1916.]

Lemme. Dans tout triangle, l'arc x (fig. 1), qui mené du sommet partage la base en deux segments α et β, est donné par

$$\cos x \sin c = \cos a \sin \beta + \cos b \sin \alpha.$$

En effet :

$$\cos a = \cos x \cos \alpha + \sin x \sin \alpha \cos \omega$$
$$\cos b = \cos x \cos \beta - \sin x \sin \beta \cos \omega.$$

Pour éliminer ω, on multiplie la première équation par $\sin \beta$, la seconde par $\sin \alpha$, et l'on additionne :

$$\cos a \sin \beta + \cos b \sin \alpha = \cos x (\sin \beta \cos \alpha + \sin \alpha \cos \beta) = \cos x \sin c.$$

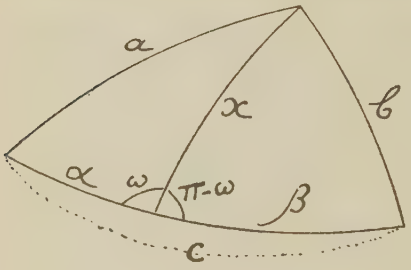

Fig. 1.

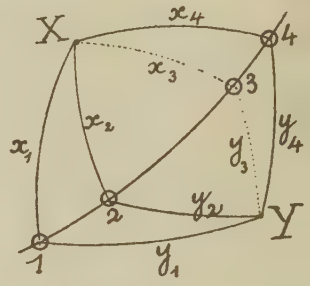

Fig. 2.

Loi de Miller.

Soient 1, 2, 3, 4 les pôles de quatre faces en zone (fig. 2), X et Y les pôles de deux axes. Dans les triangles $X14$, $Y14$, on a

$$\cos x_2 \sin \phi_{14} = \cos x_4 \sin \phi_{12} + \cos x_1 \sin \phi_{24}$$
$$\cos y_2 \sin \phi_{14} = \cos y_4 \sin \phi_{12} + \cos y_1 \sin \phi_{24},$$

et, en divisant :

$$\frac{\cos x_2}{\cos y_2} = \frac{\cos x_4 \sin \phi_{12} + \cos x_1 \sin \phi_{24}}{\cos y_4 \sin \phi_{12} + \cos y_1 \sin \phi_{24}}. \quad \ldots \quad (1)$$

Pour introduire les caractéristiques, on a

$$\frac{a}{h_1}\cos x_1 = \frac{b}{k_1}\cos y_1, \text{ ou}$$

$$\frac{a}{b}\cos x_1 = \frac{h_1}{k_1}\cos y_1.$$

En multipliant dans l'équation (1) les numérateurs par $\frac{a}{b}$, il vient:

$$\frac{h_2}{k_2} = \frac{\frac{h_4}{k_4}\cos y_4 \sin\phi_{12} + \frac{h_1}{k_1}\cos y_1 \sin\phi_{24}}{\cos y_4 \sin\phi_{12} + \cos y_1 \sin\phi_{24}}, \text{ ou}$$

$$\cos y_4 \sin\phi_{12}\left(\frac{h_2}{k_2} - \frac{h_4}{k_4}\right) = \cos y_1 \sin\phi_{24}\left(\frac{h_1}{k_1} - \frac{h_2}{k_2}\right),$$

$$\frac{\sin\phi_{12}}{\sin\phi_{24}} = \frac{\cos y_1}{\cos y_4} \cdot \frac{h_1k_2 - k_1h_2}{h_2k_4 - k_2h_4} \cdot \frac{k_4}{k_1}.$$

C'est une relation entre 1, 2, 4. En l'appliquant à 1, 3, 4, on obtient

$$\frac{\sin\phi_{13}}{\sin\phi_{34}} = \frac{\cos y_1}{\cos y_4} \cdot \frac{h_1k_3 - k_1h_3}{h_3k_4 - k_3h_4} \cdot \frac{k_4}{k_1}$$

et, en divisant:

$$\frac{\sin\phi_{12}\sin\phi_{34}}{\sin\phi_{13}\sin\phi_{24}} = \frac{(h_1k_2 - k_1h_2)(h_3k_4 - k_3h_4)}{(h_1k_3 - k_1h_3)(h_2k_4 - k_2h_4)}.$$

The crystallography and dehydration of Torbernite.

By A. F. Hallimond, M.A., F.G.S.

Assistant Curator, Museum of Practical Geology, London.

[Read November 9, 1915.]

I. Crystallography.

MEASUREMENTS for torbernite have been given by numerous observers; the results are, however, of rather early date, and although the values for the ratio $a:c$ are generally in fair agreement with the results here stated, the degree of accuracy of these measurements is not always indicated. Moreover, several minor difficulties arise, and it has been suggested that some of the early descriptions refer to the allied species, zeunerite; both species are optically uniaxial and possess almost the same axial ratios; they can, however, be distinguished by means of their refractive indices. The ordinary index of all the specimens here described has been determined by the Becke method; that for torbernite is 1·591, for the zeunerite from Schneeberg, approximately 1·62. A few torbernites possess a slightly higher index which may be due to the presence of zeunerite in isomorphous mixture, as is suggested by the presence of arsenic in some analyses.

It has been possible to examine much of the original material described by Lévy in his catalogue of the Heuland-Turner Collection (3). Before the early measurements are discussed, an account will be given of measurements made on three well-crystallized specimens of torbernite, with the object of determining more closely the crystalline form of this mineral.

The Axial Ratio of Torbernite.

Specimen No. 1[1] (fig. 1).—The locality of this specimen is not recorded. The crystals are scattered over white porous quartz; they are turbid and somewhat olive-green in colour, but the refractive index is normal

[1] No. L 1911, Museum of Practical Geology (Ludlam Collection).

and the faces are symmetrically developed and unusually free from striations and oscillatory growth. Examination of a basal cleavage flake showed that the turbidity is due to selective staining of the faces (112) during the growth of the crystals, which therefore have an 'hour-

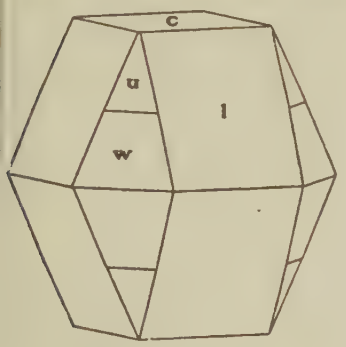

Fig. 1.—Crystal of Torbernite.

Fig. 2.—Section through crystal of fig. 1.

glass' structure; the last layer to be deposited seems to have been free from colouring matter. The appearance of a section near the middle of the crystal is shown in fig. 2.

The form $l(112)$ is normal in character, but the faces $e(101)$ are replaced by two vicinal faces separated by an angle of about 1°; these are generally equally developed, but at times one or other may be almost

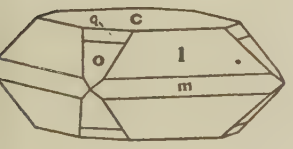

Fig. 3.

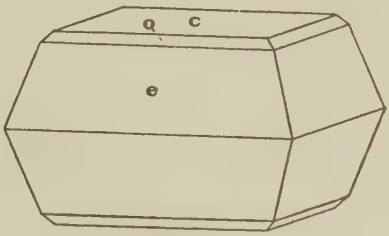

Fig. 4.

Crystals of Torbernite.

suppressed. Special care was taken to determine whether either of them was the true face $e(101)$; the readings show conclusively that neither face occupies the simple position, nor are they equally inclined to $e(101)$, they will therefore be termed u and w, without assigned

indices. A summary of the readings obtained from five crystals is given below.

Specimen No. 2[1] (fig. 3).—Rather thick, tabular crystals, transparent and of brilliant lustre, are closely grouped over the surface of white quartz. The locality is given as Redruth, but the name of the mine is not recorded. The pyramid $l(112)$ exhibits good faces, but those of $o(103)$ are often striated horizontally, and a vicinal face q occurs next the base, or in oscillatory growth. The reading for $o(103)$ is slightly below the calculated value, but importance cannot be attached to this in view of the irregularity of the faces in this zone. The faces of $m(110)$ are normal. The readings obtained from three crystals are summarized below.

Specimen No. 3[2] (fig. 4).—The locality is not recorded. The crystals are quite transparent and are very well developed. The faces of $e(101)$ are striated and the readings are unreliable even when apparently good images are obtained; the faces of $o(103)$, though narrow, give simple images for which the mean angle agrees very closely with the calculated value.

The readings obtained from this and the two preceding specimens are summarized in the following table:

Specimen.	Angle.	Limits.		Mean.	No. of readings.	Calculated.
No. 1. (Five crystals.)	$c:u(h0l)$	70° 17′	70° 50′	70° 33′	16	vicinal
	$c:w(h0l)$	71 43	72 4	71 50	10	vicinal
	$c:l(112)$	64 19	64 43	64 33	22	*64° 34′
No. 2. (Three crystals.)	$c:o(103)$	44 21	44 39	44 31	11	44 45
	$c:q(h0l)$	43 26	43 45	43 33	5	vicinal
	$c:l(112)$	64 21	64 49	64 35	16	*64 34
	$c:m(110)$	89 12	90 36	89 59	9	90 0
No. 3. (Three crystals.)	$c:o(103)$	44 39	44 56	44 47	8	44 45
	$c:e(101)$	71 3	71 45	71 18	13	71 25

[1] No. L 1890, Museum of Practical Geology (Ludlam Collection).

[2] No. L 1947, Museum of Practical Geology (Ludlam Collection).

The calculated angles are based on the mean angle $cl = 64° 34'$ for the first two specimens. The corresponding axial ratio is:

$$a : c = 1 : 2{\cdot}974.$$

The suggestion has been made by Koksharov (9) and by Walker (11) that the symmetry of torbernite is really pseudo-tetragonal, like that of autunite. The deviation from tetragonal symmetry, if present, is very small, and on account of the irregularity of growth the question cannot be decided with sufficient accuracy by the measurement of cross-ones on the crystals here described. If the faces of $e(101)$ and similar forms really belong to two closely similar zones it might be expected that the readings would be most frequent for two slightly separated values instead of for the mean. No trace of such a grouping could be found, the mean reading is also the most frequent reading, and the crystallographic evidence available is therefore in favour of the view that torbernite possesses a true axis of fourfold symmetry, a view which is very strongly supported by the optical properties and dehydration.

Comparison with earlier measurements.

The early measurements for torbernite are to be found chiefly in the text-books; they are numerous; in many cases, however, it is difficult to ascertain the experimental evidence for the readings given, and there can be little doubt that the existence of several forms has never been confirmed by actual measurement. The results given by a number of authors are summarized in the following table. The angular measurement from the base is given under each symbol so that the extent to which the readings agree may be compared. Calculated values are placed in brackets, and, in the case where an author's results are completely consistent with theory but no indication of the fundamental angle is given, it has been thought best to indicate all the angles as theoretical. The sign × signifies that the angle of an earlier author is repeated.

Phillips, 1823. (1)	Naumann, 1828. (2)	Hausmann, 1847. (4)	Miller, 1852. (5)	Dufrénoy, 1856. (6)	Greg and Lettsom, 1858. (7)	Hessenberg, 1864. (8)	Koksharov, 1866. (9)	Schrauf & Dana, 1872. (10)	A. F. H.
—	—	—	—	—	—	—	—	—	w 71° F
—	P (71° 31′)	—	—	—	—	P 71° 22′	o 71° 7′	e (71° 11′)	e (1(71° 1
—	—	—	—	—	u 70° 26′	—	—	—	u 70° 8
$c4$ 68° 10′	—	—	r (68° 15′)	$b\frac{1}{2}$ ×	r ×	—	—	r (69° 2′)	—
—	—	f (63° 22′)	—	—	—	—	—	f (62° 56′)	—
—	—	—	—	—	—	—	y (55° 33′)	y (55° 44′)	—
—	—	—	e (51° 25′)	b^1 ×	e ×	—	—	ϵ (51° 31′)	—
—	—	e (44° 55′)	—	—	—	—	x 44° 21′	o 44° 23′	o (10 44° 4
$c3$ 42° 50′	—	—	—	—	o 43° 15′	—	—	—	q 43° 3
—	—	—	—	—	—	$\frac{3}{10}P$ 41° 50′	—	z (41° 22′)	—
$c2$ 39° 20′	—	—	s (39° 53′)	$b\frac{3}{2}$ ×	s ×	—	—	s (39° 59′)	—
$c1$ 34° 28′	—	—	—	—	—	—	—	—	—
—	—	—	x (32° 4′)	b^2 ×	x ×	—	—	—	—
—	—	d (30° 53′)	—	—	—	—	—	x (30° 25′)	—
—	—	—	—	—	—	—	—	—	p (11 77° 2
—	—	—	—	—	v 72° 25′	—	—	v (72° 12′)	—
—	p (64° 42′)	—	—	$a\frac{4}{5}$ 64° 22′	l ×	—	—	l (64° 17′)	l (11 64° 3
$a2$ 46° 0′	—	c (46° 36′)	—	$a\frac{2}{5}$ (46° 10′)	t ×	—	—	t (46° 4′)	—

Notes on the preceding table.

[The numerals correspond with those in the list of references at the end of this paper, and with those at the head of the columns in the table.]

(1) Phillips says in the preface, 'in no instance has it been attempted to correct the geometry of nature'. The angles are therefore to be taken as observed values.

(2) Naumann's two values are in theoretical agreement; they are remarkably close to the later results, but it is not clear which form was measured.

(3) No angles are given in the Heuland-Turner catalogue; it seems probable that the figures are based on measurements which were used by Miller (5) and by Dufrénoy (6).

(4) Hausmann's values are in theoretical agreement with those of Naumann (2) (see Koksharov's paper (9)).

(5) These angles are in theoretical agreement; the original measured angles are not given.

(6) Dufrénoy says that these angles are based on Lévy's manuscript notes on specimens in the Turner Collection. The values are those given by Miller (5) with the addition of the forms $a\frac{4}{5}$ and $a\frac{8}{5}$, which do not accord with the rest, but are themselves in theoretical agreement. The latter values are defended by Lévy, and agree with those of other observers. The figures and symbols agree with those in the Heuland catalogue (3).

(7) Miller's angles are again quoted, with those of Lévy (3) and three new forms.

(8) For the first time the actual observation is fully recorded; the angle 71° 22′ is based on twelve measurements from five Redruth crystals; the number of readings for the other face is not given.

(9) Koksharov's result is based on a number of measurements on crystals from Cornwall and from Schlaggenwald. The material was not very good, for two measurements were rarely obtained from the same crystal. Wolf Island, Lake Onega, is quoted as the locality for one specimen which is not here described. In conclusion, the author strongly emphasizes the discordance between these results and the angles given by Miller.

(10) Schrauf wrongly quotes Wolf Island as the locality for Koksharov's material. The only new measurement given was obtained from one small Cornish crystal, and it is this angle which is taken as fundamental by Dana; the value lies between the rather widely separated results of Hessenberg and Koksharov. The suggestion is made that the early measurements of Lévy were in part made on crystals of zeunerite, the angle obtained by Schrauf for this substance agreeing with Miller's angles. Later measurements have not supported this view, the angle for zeunerite being fairly close to that for torbernite. No zeunerite was found among the English specimens examined for the purpose of the present paper.

In the last column of the table, stating my own results, only the

observed values for well-defined forms are given. Inspection of the table will show that few, if any, of the other forms are based on sufficient evidence to justify their inclusion in the list, especially in view of the confusion which has occurred between the different species of this group.

Material described by Lévy.

The early observations by Lévy (3) were made on material in the Heuland-Turner Collection. The majority of these specimens passed into the Ludlam Collection, and it has been possible to identify most of the figured specimens, which still bear numbers corresponding with those in Lévy's catalogue. The crystals are not always so well formed as might be concluded from the figures, and it is clear that the forms given have not in all cases been confirmed by measurement. The

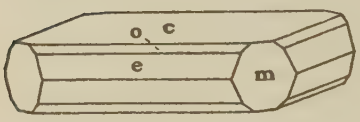

Fig. 5.

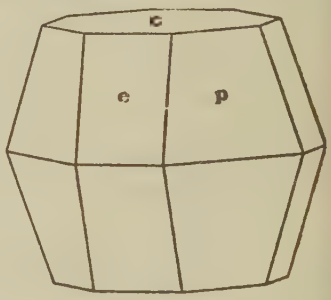

Fig. 6.

Crystals of Torbernite.

angles given later in Dufrénoy's work (6) are evidently those on which the figures are based, the high indices attributed to the pyramids $a\frac{4}{5}$ and $a\frac{8}{5}$ resulting in a very abnormal appearance in the drawings.

Measurements now made on crystals from these specimens have not confirmed the system of angles given for the forms (101), (103), &c., for the readings agree with those given in the first part of the present paper, and the form $a\frac{4}{5}$ becomes (112). The form $a\frac{8}{5}$ has not been found; it is not figured by Lévy, and it seems probable that it is based on an observation on bassetite. The habit of the crystals on most of these specimens is rather variable, and neighbouring crystals sometimes differ widely, especially in the extent to which the corners are modified by the pyramid l (112). Lévy's figures must be regarded as representing the general shape of the crystals, the forms encountered on

several crystals being brought together in the figure representing the specimen; in some cases the crystals are too small to have allowed any certain identification of the faces. The best crystal[1] from these specimens is represented in fig. 5.

The forms $c4$ *and* p (111).

The very steep form p (111), which has not previously been recorded for this mineral, was observed on crystals partially invested with bassetite.[2] A drawing of one of these crystals is given in fig. 6.

The form $c4$ of Phillips requires special consideration, since the early system of angles attributed to torbernite appears to have been based on measurements in agreement with the value of 68° 10′ assigned by Phillips to this face. Good readings for such a form have not been obtained in the course of the present measurements, but there is no doubt that some crystals have yielded confused images in this position. The faces are dull and altered and have the size and development of the common form (101). It seems probable that the reading is due to reflection from a coating of alteration product, and does not therefore represent a true form belonging to torbernite.

II. The Dehydration of Torbernite.

The perfect cleavages of torbernite render the optical study of the crushed mineral exceptionally easy; the temperature of decomposition in air lies below 100° C., and the alteration is marked by well-defined changes in the optical properties. Rinne has shown that the first and second products of dehydration, termed by him meta-torbernite[3] I and II, are not, as might be expected, amorphous bodies which retain only the external form of the crystals, but are themselves crystalline, birefringent, and are orientated in parallel position upon the still unchanged inner portions of the mineral. Rinne's description relates to the changes which occur when the mineral is heated in air; the same changes may, however, be realized at lower temperatures by the use of a desiccator. The alteration is dependent, then, jointly upon the temperature and the partial pressure of aqueous vapour in the sur-

[1] Specimen No. L 3806, Museum of Practical Geology (Ludlam Collection).

[2] A description of the specimen (No. L 1901) from Redruth has been given by the author in this volume (1915), p. 231.

[3] 'Metakupferuranit' of F. Rinne.

rounding space. The experiments here described have as chief object the determination of the limits of stability for torbernite in moist air at atmospheric pressure.

Nature of the alteration.

It is clear that the changes are due to the loss of water, the only constituent which is volatile at the temperatures in question. The second change, which yields the meta-torbernite II of Rinne, appears to be of the same character as the first; in the open air it occurs at about 130° C., but over concentrated sulphuric acid the alteration is complete at 100° C. The vapour-pressures involved are thus very low, and it is not proposed to discuss this change further in the present paper.

The first change, to meta-torbernite I, is sharply defined. If the particles are kept in an enclosure in which the vapour-pressure is higher than that indicated by the transition-curve of fig. 7, no change in their properties can be observed. As soon, however, as the conditions in the enclosure transgress the transition-curve a change sets in, which, for the coarse powder used for optical determination, is completed in about six hours. If the particles are brought back to a moister atmosphere the change is arrested; the altered portion does not, however, regain its properties, and the products may therefore be examined freely in the open air.

The square fragments are attacked from the edges, with the formation of a network of fine cracks (along the a cleavages) which gradually advances toward the centre until the whole piece is converted into a turbid and friable mass. On immersion in an oil the cracks are filled, the altered particles regain their transparency, and it can be seen that the crystal has exfoliated along the c cleavage which has been invaded by flattened air-bubbles; there is, therefore, a considerable contraction along the principal axis, as well as in the directions normal to it.

It is of interest to note that the basal cleavage planes, though presenting by far the greater area, are not directly attacked, for the central portions of the fragments remain clear until they are reached by the change proceeding from the edges. The basal planes appear, indeed, to present a barrier to the passage of water from the crystal-network, a fact which may well be connected with the close structure required for these planes, both by the steepness of the commonly occurring forms and by the perfect basal cleavage.

Optical changes.—The altered particles still exhibit an optic axis normal to the basal cleavage; the birefringence is, however, much reduced and is now positive. This in itself may not necessarily imply full crystalline symmetry, for such properties may belong to an assemblage of fibres or plates possessing only the principal axis in common. The experiments of Gaubert, who showed that crystals of barium chloride yield orientated growths upon the decomposition product as well as on the original mineral, indicate that the meta-torbernite has probably a completely crystalline structure in which the basal plane retains the symmetry, and, to some extent, the dimensions, of that in the original torbernite.

The change in birefringence is accompanied by a considerable increase in the refractive index, the ordinary index for meta-torbernite I being higher than 1·610. The extent of the alteration in a particle may be seen by immersing it in oil of the ordinary index for torbernite, in which case the border of altered material appears in relief; or by examining the flake between crossed nicols in convergent light with a lens of wide aperture, when the altered borders, having less birefringence, are relatively dark, while the unchanged torbernite appears to glow with a greenish light.

Influence of the surrounding medium.—When torbernite is placed in an enclosure containing air saturated with water-vapour at a temperature higher than 75° C., the change to meta-torbernite I takes place in accordance with the description given above. If, however, the fragments are immersed in water and brought to the same temperature, the birefringence of the resulting meta-torbernite, instead of being positive, is found to be weakly negative. The two slightly different products may be boiled in water for several hours without losing their characteristic birefringences. The temperature of transition does not appear to be influenced by the immersion of the particles, which still break down at 75° C., and the other features of the change are the same. It seems probable that the initiation of the change is dependent simply upon the vapour-pressure of the medium, and that the nature of the medium is of importance only in determining the subsequent course of the rearrangement of the crystal. It is clear that the conditions of experiment require to be stated in the fullest possible way in dealing with alterations of this character.

Method of Experiment.

The crushed torbernite was supported in small open bottles in the upper part of the test-tubes which served as desiccators. Six of these

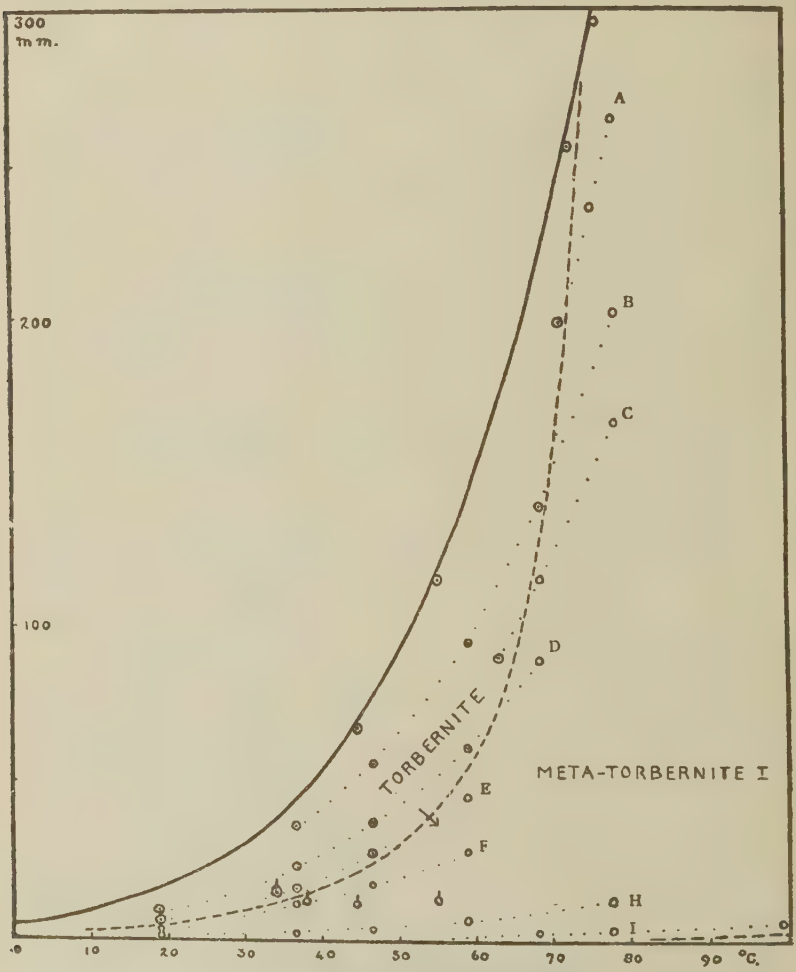

Fig. 7.—Transition-curve of Torbernite.

tubes, each containing about 20 c.c. of sulphuric acid of known concentration, were placed together in a water-bath, the temperature of which could be adjusted within limits of about one degree by means

of a thermo-regulator. After six hours the torbernite in each tube was removed and examined. The mineral in all tubes containing acids of less than a certain concentration was found to be unaltered, while that over the stronger acids had passed into meta-torbernite I. The transition-pressure at the temperature of the bath was thus determined to be between the vapour-pressures of two sulphuric acids in the series. The experiment was repeated several times for various temperatures of the water-bath. The acids used were of those concentrations for which the vapour-pressures are given in the 'Physikalisch-Chemische Tabellen' (Landolt and Börnstein), the values above 35° C. being obtained by extending the curves plotted from the tables.

A few experiments were also made by placing the torbernite in a tube, which was immersed in a water-bath and connected with a flask containing water at a constant lower temperature. The mineral was thus exposed to a vapour-pressure equal to that of the water in the cooler vessel. The results obtained were in agreement with those given by the sulphuric acids and are shown in the diagram (fig. 7). The method was found to be slow and inconvenient and was discontinued.

Results.

The conditions in a tube containing air with a known pressure of water-vapour, at a given temperature, are conveniently represented by a point on a rectangular diagram in which the ordinates measure the vapour-pressure and the abscissae the temperature. Such a diagram expresses the results of the present experiments with sufficient accuracy, and the results have therefore been directly represented in fig. 7. The unbroken line is the vapour-pressure curve of pure water. The pressures over various strengths of sulphuric acid are represented by points in the area below this line. Results for acid of one concentration are joined by a dotted line—the vapour-pressure curve of the acid in question. The following acids were used: A 24·3, B 33·1, C 37·7, D 43·7, E 52·1, F 57·6, H 73·1, I 84·4 per cent. H_2SO_4. The points within circlets represent the conditions in which the torbernite was found to be unaltered, while the vacant circlets express conditions in which the change to meta-torbernite I had occurred. The area occupied by the first class of points is the stability-field of torbernite under the present conditions. The broken line which has been drawn between the two areas is the transition-curve of torbernite, and the remaining area belongs to the stability-field of meta-torbernite I. A second transition-line

should probably be drawn in the position shown on the right of the diagram, to indicate the change to meta-torbernite II, but the correct values for the very low vapour-pressures involved have not been determined.

The four points marked in the diagram with a small vertical line represent results obtained by the second method described above. Results for acid I (84·4 per cent. H_2SO_4) were also obtained at temperatures 19°, 37°, 47°, 59° C. Meta-torbernite I was unaltered at these pressures, which are too low to be included in the diagram.

Conclusions.

The limits of temperature and vapour-pressure within which torbernite can exist are seen to be very narrow; they are, in fact, little outside the variations which occur from day to day in the condition of the atmosphere. Had the transition-curve lain a little nearer the vapour-pressure curve of pure water, it is clear that the specimens of torbernite would have passed into meta-torbernite I on the first dry day following their removal from the mine. Again, since torbernite is unstable in water at temperatures above 75° C., at least under ordinary pressure, the dilute solutions to which the crystals were exposed in the upper part of the veins cannot have exceeded this temperature since the formation of the mineral. In view of this very narrow range of stability it is not surprising to find that many specimens of torbernite have undergone more or less complete alteration; but as similar changes are brought about by chemical replacement, especially of the copper, the conclusion cannot be drawn that all these specimens have been subjected to temperatures exceeding 75° C., it is necessary first to show that the alteration product is meta-torbernite I. Nevertheless it may be regarded as probable that the majority of specimens coated externally with material of higher refractivity have undergone a partial dehydration. It is important to observe that the temperature of an exhibition-case which is liable to exposure to the direct rays of the sun might easily exceed the limit of stability for torbernite, with consequent danger to the specimens. Again, the presence of a hygroscopic body, or of a mineral capable of removing water from the air, becomes a source of danger in a closed case. The decomposition of pyrites, with the formation of the hydrated sulphate of iron, would, for instance, probably suffice for the destruction of torbernite enclosed with it, unless the necessary water was supplied by a sufficiently free communication with the atmosphere.

References.

1. W. Phillips, 'An elementary introduction to the knowledge of Mineralogy.' 3rd edit., London, 1823, p. 267.
2. C. F. Naumann, 'Lehrbuch der Mineralogie.' Berlin, 1828, p. 354.
3. A. Lévy, 'Description d'une Collection de Minéraux. . . .' London, 1837, vol. iii, p. 329.
4. J. F. L. Hausmann, 'Handbuch der Mineralogie. Theil ii.' Göttingen, 1847, vol. ii, p. 1104.
5. W. Phillips, 'An elementary introduction to Mineralogy.' New edition by H. J. Brooke and W. H. Miller, London, 1852, p. 517.
6. A. Dufrénoy, 'Traité de Minéralogie.' Paris, 1856, vol. iii, p. 321.
7. R. P. Greg and W. G. Lettsom, 'Manual of the Mineralogy of Great Britain and Ireland.' London, 1858, p. 384.
8. F. Hessenberg, 'Mineralogische Notizen.' Senckenberg. Naturf. Gesell., Abhandl. V, 1864–5, p. 273.
9. N. Koksharov, 'Materialien zur Mineralogie Russlands.' St. Petersburg, 1866, vol. v, p. 35.
10. A. Schrauf, 'Chalcolith und Zeunerit, . . .' Min. Mitth. (Tschermak), 1872, p. 181.
11. T. L. Walker, 'The crystalline symmetry of torbernite.' Amer. Journ. Sci., 1898, vol. vi, p. 41.
12. F. Rinne, 'Kupferuranit und seine Entwässerungsprodukte.' Centralblatt Min., 1901, p. 618.

Crystals of iron phosphide (Rhabdite) from a blast-furnace.

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THE crystals here described were sent by Dr. J. E. Stead, F.R.S., for crystallographic determination. They came from a 'bear' or mass of metal weighing about 300 tons that had solidified at the bottom of one of the blast-furnaces of Messrs. Cochrane & Co., Ltd., at Ormesby, near Middlesborough. They are present only in sparing amount in drusy cavities, and are absent in the mass of metal itself. These drusy cavities are lined with 'fir-tree crystallites' of metallic iron, which consist of small peg-like crystals grouped in lines along three directions at right angles. Resting on these and often extending completely across the small spaces are the bright needles of iron phosphide. The amount of material was unfortunately insufficient for a chemical analysis, but the presence of phosphorus and iron was confirmed: nickel is absent.

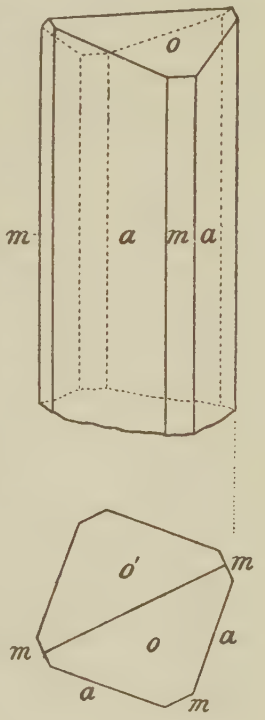
Iron phosphide is also present as a coating on the surface of the 'fir-tree crystallites', the core of which consists of metallic iron. The cavities also contain a few blade-like crystals of iron carbide; these are tin-white with brilliant metallic lustre, strongly magnetic, and very similar in general appearance to the needles of iron phosphide. Inferior measurements on the goniometer suggest that they are distorted cubic crystals flattened parallel to a face of the cube and with octahedral faces on the long edges of the blades.

The needles of iron phosphide are tin-white in colour with a brilliant metallic lustre, and sometimes a yellowish tarnish. They are brittle, and break with a sub-conchoidal cross-fracture. They are strongly magnetic, being readily attracted by a magnetic needle. In length they range from 1 to 3 mm. and in thickness 0·1–0·25 mm. They have the form of square prisms truncated on their edges by planes at 45°. The

faces, however, often vary considerably in relative size: some are absent or visible only on the goniometer as a mere line, whilst others are largely developed, sometimes giving rise to a more or less pronounced platy habit of the crystals. The best goniometric readings in this prism-zone on several crystals were 44° 57′, 45° 0′, 45° 2′, 45° 4′, &c. The crystals are therefore presumably tetragonal.

Only three crystals with terminal faces were found, each of which shows only two pyramidal faces, as represented in the accompanying text-figure. This distribution of faces points to the symmetry being that of the scalenohedral or sphenoidal-hemihedral class of the tetragonal system, of which copper-pyrites is a well-known example. It is possible, however, that the class may be the sphenoidal-tetartohedral, but no doubly-terminated crystals have been observed. Etched figures would decide this point; but none could be produced. The best measurement obtained from a terminal face was the angle $mo = 63° 52′$, from which is calculated the axial ratio

$$a : c = 1 : 0{\cdot}3469.$$



Crystal of Iron phosphide. (Sphenoidal-hemihedral tetragonal.)

On another crystal $mo = 63° 54′$. The readings oo' on the three crystals were 51° 51′, 52° 6′, and 52° 45′, mean 52° 14′; and the mean of all readings (mo and oo') gave $oo' = 52° 15′$. The only forms present on the crystals are $a\{100\}$, $m\{110\}$, and $o\{111\}$.

Tetragonal crystals of iron phosphide have been previously measured and described by E. Mallard and by C. Hlawatsch. Crystals having the form of a right prism on a square base were prepared artificially by T. Sidot[1] in 1872; whilst still earlier, according to P. Daubrée,[2] prismatic crystals

[1] T. Sidot, 'Production d'un phosphure de fer cristallisé.' Compt. Rend. Acad. Sci. Paris, 1872, vol. lxxiv, p. 1425.

[2] P. Daubrée, 'Observations relatives au phosphure de fer cristallisé obtenu

of undetermined system had been made by Boblique. Mallard's[1] crystals had been formed by the burning of a coal seam at Commentry in France. They showed the same forms as the crystals now described, except that they were terminated by four pyramidal faces. Hlawatsch's[2] crystals were found in a mass of slag and iron in a blast-furnace at Beraun in Bohemia. These again showed the tetragonal forms $a\{100\}$, $m\{110\}$, and $o\{111\}$, but with only two, instead of four, pyramidal faces. Hlawatsch therefore suggested that the crystals belonged to the scalenohedral class.

The few angles that have been measured on the crystals from these three sources are tabulated below; they are in sufficiently close agreement to establish the identity of the materials.

Angle.	Mallard (1881).	Hlawatsch (1903).	Spencer.	
			Measured.	Calculated.
$oo' = 111 : \bar{1}\bar{1}1$	—	*52° 10′	52° 14′	52° 16′
$oo = 111 : \bar{1}11$	36° 18′	—	—	36 18
$mo = 110 : 111$	—	—	*63 52	—
$ao = 100 : 111$	*71 56	—	71 46	71 51
Axis c	0·3451	0·3462	—	0·3469

Although several phosphides of iron have been prepared in the laboratory, unfortunately the chemical composition of definitely crystallized material has not been satisfactorily determined. Sidot gave the composition as Fe_4P, whilst Mallard's material, analysed by A. Carnot, led to the formula Fe_7P_2. It is not, however, clear from the original descriptions whether these analyses were made on separated tetragonal crystals or on the associated crystalline mass. Dr. J. E. Stead[3] arrived

par M. Sidot.' Ibid., p. 1427. Boblique, Bull. Soc. Chim. Paris, 1866, vol. v, p. 248.

[1] E. Mallard, 'Sur la production d'un phosphure de fer cristallisé et du feldspath anorthite dans les incendies des houillères de Commentry.' Compt. Rend. Acad. Sci. Paris, 1881, vol. xcii, p. 933; Bull. Soc. Min. France, 1881, vol. iv, p. 230.

[2] C. Hlawatsch, 'Zwei krystallisierte Hüttenprodukte von Beraun.' Min. Petr. Mitt. (Tschermak), 1903, vol. xxii, p. 497.

[3] J. E. Stead, 'Iron and phosphorus.' Journ. Iron and Steel Inst., 1900, vol. lviii (No. ii for 1900), p. 79, plate IV, fig. 5. Similar outlines would be given by chance sections of the tetragonal crystals described above.

at the composition Fe_3P for crystallized material which showed rhomb-shaped outlines in section.

Iron phosphide has not been observed as a terrestrial mineral, but the frequent presence of iron-nickel phosphide, $(Fe,Ni)_3P$, containing about 15 to 30 per cent. of nickel replacing an equivalent amount of iron, has long been known in meteoric irons and stones, having been first detected by Berzelius in 1832. This was named schreibersite by W. Haidinger in 1847; and in 1864 G. Rose described acicular crystals, belonging to the tetragonal system, which he named rhabdite. Schreibersite and rhabdite have since been proved to be identical, although the latter name is still applied to crystals of the acicular habit as distinct from those of the platy habit. Figures of rhabdite crystals have been given by E. Cohen[1] and by E. Hussak,[2] but without satisfactory measurements capable of direct comparison with those given above. Nevertheless the identity of the artificial and meteoric crystals has been frequently assumed.

[1] E. Cohen and E. Weinschenk, 'Meteoreisen-Studien.' Ann. k. k. naturhist. Hofmuseums, Wien, 1891, vol. vi, p. 139. E. Cohen, 'Meteoreisen-Studien, III.' Ibid., 1894, vol. ix, p. 108. E. Cohen, 'Meteoritenkunde,' Stuttgart, 1894, pp. 125–128.

[2] E. Hussak in O. A. Derby, 'Estudo sobre o meteorito de Bendigó.' Archivos do Museu Nacional do Rio de Janeiro, 1896, vol. ix, p. 171.

A (seventh) list of new mineral names.[1]

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Aloxite. (The Mineral Industry, New York, vol. xxii for 1913, 1914, p. 1.) Trade-name for a form of fused crystalline alumina, or artificial corundum, manufactured by the Carborundum Company, and used for abrasive purposes.

Alumogel. O. Pauls, 1913. Zeits. prakt. Geol., Jahrg. xxi, p. 545. Amorphous aluminium hydroxide of indefinite composition forming the main constituent of bauxite. Compare Diasporogelite.

Amberine. (D. B. Sterrett, Gems and precious stones in 1913, Mineral Resources of the United States, for 1913, 1914, part ii, p. 652.) Local trade-name, used by Mr. Joseph Ward, of Barstow, California, for a yellowish-green chalcedony from the Death Valley region, California.

Angaralite. A. Meister, 1910. Explorations géologiques dans les régions aurifères de la Sibérie, Région aurifère d'Iénisséi, Livraison IX, 1910, p. 506 (ангаралить), p. 667 (Angaralite); abstract in Zeits. Kryst. Min., 1914, vol. liii, p. 597 (*Angaralith*). Silicate of aluminium, iron, and magnesium, $2MgO\,.\,5(Al,Fe)_2O_3\,.\,6SiO_2$, occurring as thin, black plates (optically uniaxial and positive, and perhaps hexagonal) in metamorphosed limestone near the Angara river, Siberia. (*See* Tatarkaite.)

Aurobismuthinite. G. A. Koenig, 1912. Journ. Acad. Nat. Sci. Philadelphia, ser. 2, vol. xv, p. 423. A lead-grey, massive, cleavable mineral from unknown locality, consisting mainly of bismuth sulphide with Au 12·27 per cent. and Ag 2·32 per cent.; formula, $(Bi,Au,Ag_2)_5S_6$. This may represent a mixture of $(Bi,Au,Ag_2)S$, or possibly of a gold-silver alloy, and bismuthinite (Bi_2S_3). *See* Stibiobismuthinite.

[1] Previous lists of this series have been given at the ends of vols. xi–xvi (1897–1913) of this Magazine.

Barthite. M. Henglein and W. Meigen, 1914. Centralblatt Min., 1914, p. 353 (Barthit). A hydrated arsenate of zinc and copper, $3ZnO . CuO . 3As_2O_5 . 2H_2O$, occurring as grass-green, crystalline (monoclinic?) crusts in dolomite at Guchab, Otavi, South-West Africa. Named after Mr. — Barth, mining engineer at Guchab, who collected the material.

Baryt-Flussspath. *See* Fluobaryt.

Basitom-Glanz. A. Breithaupt, 1832. Vollständige Charakteristik des Mineral-Systems, 3rd edit., p. 267 (Staurotyper Basitom-Glanz). Apparently so named because of the supposed existence of a basal cleavage. An obsolete synonym of freieslebenite.

Bassetite. A. F. Hallimond, 1915. Mineralogical Magazine, vol. xvii, p. 221. A yellow 'uranium-mica' from the Basset mines, Redruth, Cornwall, hitherto referred to autunite, but now shown to be distinct from the original autunite from Autun in France. It is monoclinic with the probable composition $Ca(UO_2)_2(PO_4)_2 . 8H_2O$. Named after the locality.

Bazzite. E. Artini, 1915. Atti (Rend.) R. Accad. Lincei, Roma, ser. 5, vol. xxiv, sem. 1, p. 313. Minute, sky-blue, hexagonal prisms and barrel-shaped crystals occurring sparingly in the drusy cavities of the granite of Baveno, Piedmont. A preliminary chemical analysis shows them to consist of silicate of scandium with other rare-earth metals, iron, and a little sodium. Named after the engineer E. Bazzi, who collected the material.

Belbaite. V. I. Vernadsky, 1913. *See* Elbaite.

Bilinite. J. Šebor, 1913. [Sborník Klubu přírodovědeckého, Prag, 1913, no. II.] Abstract in Neues Jahrb. Min., 1914, vol. i, Ref. 395 (Bilinit). An iron-alum, $Fe''Fe'''_2S_4O_{16} . 24H_2O$, the iron analogue of halotrichite, occurring as white to yellowish, radially-fibrous masses in lignite at Schwaz, near Bilin, Bohemia.

Bisbeeite. W. T. Schaller, 1915. Journ. Washington Acad. Sci., vol. v, p. 7; Third Appendix to 6th edit. of Dana's System of Mineralogy, p. 14. A fibrous, orthorhombic, pale-blue hydrated silicate of copper, $CuSiO_3 . H_2O$, resulting from the hydration of shattuckite (q.v.). Named from the locality, Bisbee, Arizona.

Bixbite. (A. Eppler, Die Schmuck- und Edelsteine, Stuttgart, 1912, p. 253 (Bixbit).) A gooseberry-red beryl found to the south-west of Simpson Spring, Utah.

Bütschliite. R. Lang, 1914. Neues Jahrb. Min., Beil.-Bd. xxxviii, p. 150 (Bütschliit). Amorphous calcium carbonate represented by the freshly precipitated material and also present in the hard parts of certain organisms. Named after Otto Bütschli, Professor of Zoology in the University of Heidelberg.

Calcio-carnotite. E. T. Wherry, 1914. Science, New York, new ser., vol. xxxix, p. 576; Bull. United States Geol. Survey, no. 580, p. 149. W. F. Hillebrand, H. E. Merwin, and F. E. Wright, Proc. Amer. Phil. Soc., 1914, vol. liii, p. 38. A synonym of tyuyamunite (sixth list). *See* Kalio-carnotite.

Calcioscheelite. E. T. Wherry, 1914. Proc. United States National Museum, vol. xlvii, p. 504. Synonym of scheelite.

Carbonate-marialite and **Carbonate-meionite.** L. H. Borgström, 1914. Zeits. Kryst. Min., vol. liv, p. 252. The chemical composition of the minerals of the scapolite group is explained by the isomorphous mixing of the following hypothetical molecules:

Chloride-marialite (Chloridmarialit)	$NaCl \cdot 3NaAlSi_3O_8$
Sulphate-marialite (Sulfatmarialit)	$Na_2SO_4 \cdot 3NaAlS_3O_8$
Carbonate-marialite (Karbonatmarialit)	$Na_2CO_3 \cdot 3NaAlSi_3O_8$
Carbonate-meionite (Karbonatmejonit)	$CaCO_3 \cdot 3CaAl_2Si_2O_8$
Sulphate-meionite (Sulfatmejonit)	$CaSO_4 \cdot 3CaAl_2Si_2O_8$.

The existence of an *oxide-meionite* (oxydmejonit) molecule, $CaO \cdot 3CaAl_2Si_2O_8$, assumed by G. Tschermak (1883), is doubted. R. Brauns (Neues Jahrb. Min., 1915, vol. ii, Ref. p. 141), however, suggests that there may be *oxydhydratmejonit* and *oxydhydratmarialith*. Compare Silvialite.

Cebollite. E. S. Larsen and W. T. Schaller, 1914. Journ. Washington Acad. Sci., vol. iv, p. 480. A hydrated silicate of calcium, aluminium, &c., $H_4Al_2Ca_5Si_3O_{16}$, forming a dull, compact, white to greenish, fibrous (orthorhombic?) aggregate. It occurs as an alteration product of melilite at Cebolla Creek, Gunnison Co., Colorado. Named after the locality. Compare Deeckeite.

Cerfluorite. T. Vogt, 1914. Neues Jahrb. Min., vol. ii, p. 15 (Cerfluorit). Artificial, cubic mixed crystals of calcium and cerium fluorides, $(Ca_3, Ce_2)F_6$, analogous to the mineral yttrofluorite (T. Vogt, 1911; sixth list), and mixed with this forming the mineral yttrocerite.

Chillagite. A. T. Ullmann, 1913. Journ. R. Soc. New South Wales, vol. xlvi (for 1912), p. 186; C. D. Smith and L. A. Cotton, ibid., p. 207. Tungstate and molybdate of lead, $PbWO_4 . PbMoO_4$, intermediate between stolzite and wulfenite, forming yellow, platy, tetragonal crystals. Named after the locality, Chillagoe, Queensland. In a mineral-dealer's circular (F. Krantz of Bonn, November 1912; advertisement in Nature, London, September 12, 1912) the name *Lionit* or *Lyonite* has been applied to this mineral, after Mr. D. Lyon, the manager of the Christmas Gift mine in which it was found.

Chloride-marialite. L. H. Borgström, 1914. *See* Carbonate-marialite.

Chloritite. J. Samojlov, 1906. Materialui Geol. Rossii (Imperial Mineralogical Society, Petrograd), vol. xxiii, p. 204 (Хлоритить); abstract in Neues Jahrb. Min., 1907, vol. ii, Ref. p. 196 (Chloritit). A name proposed for V. I. Vernadsky's hypothetical chlorite acid, $H_2Al_2SiO_6$ (Min. Mag., 1902, vol. xiii, p. 128). The name *α-chloritite* is applied to a scaly chloritic mineral, from the Donetz Basin in south-east Russia, approximating to the above in composition, $4Al_2O_3 . 5SiO_2 . 7H_2O$.

Chrome-idocrase. British Museum (Natural History), The Student's Index to the Collection of Minerals, 1914, 25th edit., p. 9. An emerald-green variety of idocrase containing chromium, from the Montreal Chromite pit, Black Lake, Megantic Co., Quebec, and from the Monetnaya estate, Ekaterinburg, Urals.

Cobaltnickelpyrite. M. Henglein, 1914. Centralblatt Min., 1914, p. 129 (*Kobaltnickelpyrit*). A member of the pyrites group containing considerable amounts of nickel (11·7–17·5 per cent.) and cobalt (6·6–10·6 per cent.), $(Fe,Ni,Co)S_2$; occurring as steel-grey, pentagonal-dodecahedral crystals at Müsen, Westphalia.

V. I. Vernadsky (Centralblatt Min., 1914, p. 494) points out that he had previously, in his Russian textbook on mineralogy (1910), applied this name to cobaltiferous (2·0–3·5 per cent.) and nickeliferous (2·2–5·8 per cent.) iron-pyrites. If these are not identical, he suggests that Henglein's mineral is perhaps $(Co,Ni,Fe)S_2$ intermixed with some iron-pyrites. The same name (Cobalt-nickel pyrites) has appeared, as a

synonym of linnaeite, in the British Museum Index of Minerals since 1863.

Custerite. J. B. Umpleby, W. T. Schaller, and E. S. Larsen, 1913, Amer. Journ. Sci., ser. 4, vol. xxxvi, p. 385; Zeits. Kryst. Min., 1914, vol. liii, p. 321. A monoclinic, hydrous fluosilicate of calcium, $Ca_2(OH,F)_2SiO_3$, occurring as finely granular masses, resembling greenish marble in appearance, at a limestone-granite contact in Custer County, Idaho. Named from the locality.

Deeckeite. J. Soellner, 1913. Mitt. Badischen Geol. Landesanstalt, vol. vii, p. 436 (Deeckëit). A hydrated silicate, $(H,K,Na)_2(Mg,Ca)(Al,Fe)_2(Si_2O_5)_5 . 9H_2O$, allied to ptilolite and mordenite, occurring as a pseudomorph after melilite in a dyke rock (bergalith) in the Kaiserstuhl, Baden. The characteristic 'peg-structure' of melilite is a result of the partial alteration of this mineral to deeckeite. Named after Professor Wilhelm Deecke, Director of the Geological Survey of Baden.

Diasporogelite. F. Tućan, 1913. Centralblatt Min., 1913, p. 768 (Diasporogelit). A more correct form of the name Sporogelite (sixth list). Similarly, *Pyritogelit*, *Limonitogelit*, *Hämatitogelit*, and *Gibbsitogelit*, for the colloidal forms corresponding to the minerals, pyrites, &c. E. T. Wherry (Centralblatt Min., 1913, p. 519) had previously proposed to distinguish these colloidal forms as *κ-Diaspor*, *κ-Pyrit*, &c., from the initial letter of *κόλλα*.

Dufreniberaunite. E. T. Wherry, 1914. Proc. United States National Museum, vol. xlvii, p. 509. A hydrated ferric (and manganic) phosphate from Hellertown, Pennsylvania, intermediate in composition between dufrenite and beraunite, and possibly a mixture of these species, but referred by the author to the species beraunite.

Elbaite. V. I. Vernadsky, 1913. Zeits. Kryst. Min., vol. liii, p. 283 (Elbait). The chemical composition of the tourmalines is expressed by the mixing of three hypothetical molecules (additive derivatives of the kaolin ring), namely $A = M'_6Al_4B_2Si_4O_{21}$, $B = M'_{14}Al_2B_2Si_4O_{21}$, and $C = M'_2Al_6B_2Si_4O_{21}$. These hypothetical components of tourmaline are named *kalbaite*, *belbaite*, and *elbaite* respectively. The pale red tourmaline from the Island of Elba consists of nearly pure elbaite, and that from DeKalb in New York of nearly pure kalbaite; hence these names. Belbaite is apparently from elbaite with *B* prefixed. The name elbaite has previously been applied (C. L. Giesecke, 1832) to ilvaite from Elba.

Empressite. R. D. George in MS., quoted by W. M. Bradley, 1914. Amer. Journ. Sci., ser. 4, vol. xxxviii, p. 163; ibid., 1915, vol. xxxix, p. 223. A telluride of silver, AgTe, found as pale bronze-coloured, finely granular masses in the Empress-Josephine mine, Kerber Creek district, Colorado.

W. T. Schaller (Journ. Washington Acad. Sci., 1914, vol. iv, p. 497) suggests that this is identical with the muthmannite of F. Zambonini (1911, sixth list), being a pure muthmannite, whilst the original muthmannite should be called an auric muthmannite, (Ag,Au)Te.

Epidesmine. V. Rosický and S. J. Thugutt, 1913. Spraw. Tow. Nauk. Warsawa, vol. vi, pp. 225, 231; Centralblatt Min., 1913, p. 422 (Epidesmin). An orthorhombic zeolite, $3(Ca,Na_2,K_2)Al_2Si_6O_{16} . 20H_2O$, dimorphous with stilbite (Germ. Desmin), occurring as minute crystals at Schwarzenberg, Saxony. The name is suggested from the similar dimorphous pair epistilbite and heulandite (Germ. Stilbit).

β-Eukryptit. *See* Pseudo-eucryptite.

Faratsihite. A. Lacroix, 1915. Bull. Soc. franç. Min., vol. xxxvii (for 1914), p. 231. A canary-yellow, compact mineral resembling nontronite in colour and kaolinite in structure, and intermediate in composition, $(Al,Fe)_2O_3 . 2SiO_2 . 2H_2O$, between these two species. Occurs with opal filling veins in decomposed phonolitic trachyte near Faratsiho, Madagascar. Named from the locality.

Fernandinite. W. T. Schaller, 1915. Journ. Washington Acad. Sci., vol. v, p. 7; Third Appendix to 6th edit. of Dana's System of Mineralogy, p. 29. A massive, dull-green, hydrated vanadate of calcium and vanadyl, $CaO . V_2O_4 . 5V_2O_5 . 14H_2O$. From Minasragra, Peru. Named after Mr. Eulagio E. Fernandini, the former owner of the vanadium deposit at this locality.

Ferriallophane. F. A. Nikolaevski, 1914. Bull. Acad. Sci., St. Pétersbourg, ser. 6, vol. viii (1), p. 147 (Ферри-аллофанъ), p. 150 (Ферриаллофанъ). A variety of allophane containing much iron (Fe_2O_3 21–25 per cent.), occurring as dark-brown, colloidal masses in dolomite near Moscow. This and the ochreous clays, sinopite, melinite, ochran, and plinthite, are included in a group of *ferriallophanoids* (compare allophanoids, S. J. Thugutt, 1911; sixth list).

Ferrimolybdite. P. Pilipenko, 1914. [Festschrift V. I. Vernadsky, Beilage z. d. Mater. z. Kenntnis d. geol. Baues d. Russ. Reichs, Moskau.]

Abstract in Neues Jahrb. Min., 1915, vol. ii, Ref. 191 (Ferrimolybdit). The mineral long known as molybdic ochre or molybdite was shown by W. T. Schaller in 1907 to be a hydrated ferric molybdate ($Fe_2O_3 . 3MoO_2 . 7\frac{1}{2}H_2O$) rather than molybdenum trioxide, and he suggested that if the latter compound be ever found as a mineral the former should receive a distinctive name: this is now supplied by P. Pilipenko, whose analysis of material from Siberia leads to the formula $2Fe_2O_3 . 7MoO_3 . 19H_2O$. The analogous term ferritungstite has been introduced by Schaller (1911; sixth list) under similar circumstances.

Ferroprehnite. R. A. A. Johnston, 1913. Victoria Memorial Museum, Geol. Survey Canada, Bull. no. 1, p. 98; A List of Canadian mineral occurrences, Canada, Dept. of Mines (Geol. Survey), 1915, Memoir 74 (Geol. Ser. 61), p. 183. A variety of prehnite rich in iron (Fe_2O_3 6·58 per cent.) from Baffin Island, Arctic Canada.

Ferrorhabdite. (A. Lacroix, Minéralogie de la France, 1909, vol. iii, p. 618.) Synonym of rhabdite.

Fizelyite. (F. Krantz's Circular of January 1914, pp. 3, 5; Third Appendix to 6th edit. of Dana's System of Mineralogy, 1915, p. 30.) Black, striated, acicular crystals associated with semseyite, galena, sphaerosiderite, and quartz, from Kisbánya, Torda-Aranyos, Hungary. Said to be monoclinic and with the composition $5PbS . Ag_2S . 4Sb_2S_3$.

Fluobaryt. J. F. L. Hausmann, 1847. Handbuch der Mineralogie, vol. ii, p. 1441. A compact mixture of fluorite and barytes from Derbyshire analysed by J. Smithson (Ann. Phil., 1820, vol. xvi, p. 48). It was thought to represent a definite compound and was earlier referred to as *Fluss-Schwerspath* (Journ. für Chemie und Physik, 1821, vol. xxxi, p. 362), and *Baryt-Flussspath* (Berzelius's Jahres-Ber., 1822, vol. ii, p. 102).

Fremontite. W. T. Schaller, 1914. Journ. Washington Acad. Sci., vol. iv, p. 356; Third Appendix to 6th edit. of Dana's System of Mineralogy, 1915, p. 31. To replace the earlier name Natramblygonite or Natronamblygonit (W. T. Schaller, 1911; sixth list). Named from the locality, Fremont County, Colorado. *See* Natromontebrasite.

Furnacite. A. Lacroix, 1915. Bull. Soc. franç. Min., vol. xxxviii, p. 198. Confused groups of small, dark olive-green crystals (monoclinic?) occurring on dioptase from the French Congo. A preliminary examination suggests that the mineral is a basic chromo-arsenate of

lead and copper analogous to vauquelinite (chromo-phosphate of lead and copper). Named from 'furnax' [error for the Latin *fornax*] in honour of the colonial governor, Mr. Lucien Fourneau.

Galafatite. (Engineering and Mining Journ., New York, 1911, vol. xci, p. 261; Mining Magazine, London, 1911, vol. iv, p. 229; Zeits. Kryst. Min., 1914, vol. liv, p. 80; Third Appendix to 6th edit. of Dana's System of Mineralogy, 1915, p. 3.) Error for Calafatite (S. Calderón, 1910; sixth list).

Gibbsitogelit. *See* Diasporogelite.

Grossouvreite. S. Meunier, 1902. Bull. Soc. Géol. France, ser. 4, vol. ii, p. 250. A. Lacroix, Minéralogie de la France, 1913, vol. v, p. 50 (grossouvréite). To replace the preoccupied name vierzonite of Albert de Grossouvre (1901; third list) for a pulverulent opal from Vierzon, dép. Cher.

Grothine. F. Zambonini, 1913. Atti (Rend.) R. Accad. Lincei, Roma, ser. 5, vol. xxii, sem. 1, p. 801 (Grothina). Small, colourless, orthorhombic crystals found in metamorphic limestone at Nocera and Sarno, Campania, Italy. Qualitative tests point to a silicate of aluminium (with a trace of iron) and calcium. Named after Professor Paul Heinrich von Groth, of Munich. Not the Grothite of J. D. Dana, 1867.

Hämatitogelit. *See* Diasporogelite.

Halitkainit. *See* Thanite.

Hartsalzkainitit. *See* Thanite.

Hematogelite. (Third Appendix to 6th edit. of Dana's System of Mineralogy, 1915, p. 37.) Another spelling of Haematogelite (F. Tućan, 1913; sixth list).

Hewettite. W. F. Hillebrand, H. E. Merwin, and F. E. Wright, 1914. Proc. Amer. Phil. Soc., vol. liii, p. 32; Zeits. Kryst. Min., vol. liv, p. 209. An orthorhombic, hydrous vanadate of calcium, $CaO.3V_2O_5.9H_2O$, forming mahogany-red, silky aggregates of minute needles, and occurring as an oxidation product of patronite at Minasragra, Peru. Named after Mr. D. Foster Hewett, of the United States Geological Survey. An isomeric form is called *metahewettite* (q. v.).

Hodgkinsonite. C. Palache and W. T. Schaller, 1913. Journ. Washington Acad. Sci., vol. iii, p. 474; ibid., 1914, vol. iv, p. 153; Zeits. Kryst. Min., 1914, vol. liii, pp. 529, 675. Hydrous silicate of

zinc and manganese, $MnO . 2ZnO . SiO_2 . H_2O$, occurring as pink, monoclinic crystals at Franklin Furnace, New Jersey. Named after Mr. H. H. Hodgkinson, of Franklin Furnace.

Holmquistite. A. Osann, 1913. Sitzungsber. Heidelberg. Akad. Wiss., Abt. A, Abh. 23 (Holmquistit; *Lithionglaukophan*). A blue amphibole with the optical characters of glaucophane, but containing lithium and little sodium (Li_2O 2·13, Na_2O 1·12 per cent.), occurring in a granulitic rock on the island of Utö near Stockholm. Named after Professor Per Johan Holmquist of Stockholm.

Hügelite. V. Dürrfeld, 1913. Zeits. Kryst. Min., vol. liii, p. 183 (Hügelit). A hydrated vanadate of lead and zinc occurring as yellow, monoclinic needles on corroded galena at Reichenbach, Baden. Previously described, but without a name, by the same author (loc. cit., 1912, vol. li, p. 278). Named after Baron Hügel.

Inyoite. W. T. Schaller, 1914. Journ. Washington Acad. Sci., vol. iv, p. 355; Third Appendix to 6th edit. of Dana's System of Mineralogy, 1915, p. 41. Hydrated calcium borate, $2CaO . 3B_2O_3 . 13H_2O$, found as large, colourless, monoclinic crystals in the borate deposits in Inyo County, California. Named from the locality. The material is largely altered to Meyerhofferite (q. v.).

Jadeite-Aegirite. R. Doht and C. Hlawatsch, 1913. Verh. Geol. Reichsanst. Wien, 1913, p. 88 (Jadeit-Ägirin). An aegirite-like pyroxene from Golling, Salzburg, which, in addition to the aegirite molecule $NaFeSi_2O_6$, also contains the jadeite molecule $NaAlSi_2O_6$ in considerable amount.

Ježekite. F. Slavík, 1914. [Memoirs Bohemian Acad. Sci.]; Doelter's Handbuch der Mineralchemie, vol. iii, p. 491; Bull. Soc. franç. Min., vol. xxxvii, p. 153. Colourless to white, monoclinic crystals, somewhat resembling epistilbite in appearance, occurring with lacroixite and roscherite (q. v.) in drusy cavities in lithionite-granite at Greifenstein, near Ehrenfriedersdorf, Saxony. It is a basic fluophosphate of aluminium, calcium, and sodium with a little lithium, $Na_4CaAl(AlO)P_2O_8F_2(OH)_2$, and is closely allied to morinite. Named after Dr. Bohuslav Ježek, of the Bohemian Museum at Prague.

Kalbaite. V. I. Vernadsky, 1913. *See* Elbaite.

Kalio-carnotite. E. T. Wherry, 1914. Science, New York, new ser., vol. xxxix, p. 576. The original carnotite containing potassium,

as distinct from calcio-carnotite (q. v.). In another place (Bull. United States Geol. Survey, 1914, no. 580, p. 149) the same author employs the term *potassio-carnotite.*

Kobaltnickelpyrit. *See* Cobaltnickelpyrite.

Koechlinite. W. T. Schaller, 1914. Journ. Washington Acad. Sci., vol. iv, p. 354; Third Appendix to 6th edit. of Dana's System of Mineralogy, 1915, p. 43. A molybdate of bismuth, $Bi_2O_3 . MoO_3$, as minute, greenish-yellow, orthorhombic plates, nearly square in outline with perfect platy cleavage, and resembling torbernite in appearance. From Schneeberg, Saxony. Detected on a single specimen preserved in the mineral collection of the Natural History Museum at Vienna. Named after Dr. Rudolf Koechlin, Curator of that collection.

Kundaite. B. Doss, 1914. Centralblatt Min., 1914, p. 613 (Kundait). A variety of grahamite distinguished by the brown colour of its powder and by its greater solubility in oil of turpentine and in chloroform. Named from the locality, Kunda, Esthonia.

Lacroixite. F. Slavík, 1914. [Memoirs Bohemian Acad. Sci.]; Doelter's Handbuch der Mineralchemie, vol. iii, p. 492; Bull Soc. franç. Min., vol. xxxvii, p. 157. Imperfect crystals with an orthorhombic aspect and resembling herderite, but probably monoclinic, occurring with ježekite and roscherite (q. v.) in drusy cavities in lithionite-granite at Greifenstein, near Ehrenfriedersdorf, Saxony. It is a hydrated basic fluophosphate of aluminium, calcium, manganese, and sodium, $3AlPO_4 . 4(Ca,Mn)O . 4Na(F,OH) . 2H_2O$. Named after Prof. Alfred Lacroix, of Paris. Not the Lacroisite of H. Lienau (1903; third list).

Laneite. G. Munteanu-Murgoci, 1906. Bull. Dept. Geol. Univ. California, vol. iv, p. 384. A variety of amphibole occurring in riebeckite rocks. It is dark coloured with very strong pleochroism. Optically negative and uniaxial or with very small axial angle, the axial plane being perpendicular to the plane of symmetry; $c : t = 13–26°$. Named after Prof. Alfred Church Lane, of Tuft's College, Massachusetts.

Lechatelierite. A. Lacroix, 1915. Bull. Soc. franç. Min., vol. xxxviii, pp. 182, 198 (lechatelièrite). Naturally occurring fused (amorphous) silica (silica glass), observed in fulgurites and in quartzose enclosures in volcanic rocks. Named after Professor Henri Le Chatelier, of Paris.

Limonitogelit. *See* Diasporogelite.

Lionit. *See* Chillagite.

Lithionglaukophan. *See* Holmquistite.

Lucinite. W. T. Schaller, 1914. Journ. Washington Acad. Sci., vol. iv, p. 355; Third Appendix to 6th edit. of Dana's System of Mineralogy, 1915, p. 46. Green, orthorhombic crystals of octahedral habit occurring with tabular orthorhombic crystals of variscite, with which they are identical in composition, $Al_2O_3 . P_2O_5 . 4H_2O$. Named from the locality, Lucin, Utah.

Lyonite. *See* Chillagite.

Magnesioscheelite. E. T. Wherry, 1914. Proc. United States National Museum, vol. xlvii, p. 504. A hypothetical magnesium tungstate, $MgWO_4$, isomorphous with scheelite.

Makinthosit. C. Doelter, Handbuch der Mineralchemie, 1913, vol. iii, p. 234. Error for Mackintoshite.

Metabrucite. F. Rinne, 1913. Fortschritte Min. Krist. Petr., vol. iii, p. 160 (Metabrucit); O. Westphal, Inaug.-Diss., Leipzig, 1913. Brucite, $Mg(OH)_2$, artificially dehydrated, but retaining its original crystalline structure.

Metahewettite. W. F. Hillebrand, H. E. Merwin, and F. E. Wright, 1914. Proc. Amer. Phil. Soc., vol. liii, p. 33; Zeits. Kryst. Min., vol. liv, p. 209. An orthorhombic, hydrous vanadate of calcium, $CaO . 3V_2O_5 . 9H_2O$, occurring as a dark-red powdery impregnation in sandstone in Colorado and Utah. It differs slightly from hewettite (q. v.) in its behaviour during dehydration.

Meta-torbernite. A. F. Hallimond, 1916. Mineralogical Magazine, vol. xvii, p. 333. Synonym of Metakupferuranit (F. Rinne, 1901) and Metachalcolite (third list).

Meyerhofferite. W. T. Schaller, 1914. Journ. Washington Acad. Sci., vol. iv, p. 355; Third Appendix to 6th edit. of Dana's System of Mineralogy, 1915, p. 50. Hydrated calcium borate, $2CaO . 3B_2O_3 . 7H_2O$, occurring as colourless, triclinic crystals or as a white, fibrous alteration product of Inyoite (q. v.) in the borate deposits of Mt. Blanco district, Inyo Co., California. Named after Wilhelm Meyerhoffer (1864–1906), of Berlin, who, in association with J. H. van't Hoff, prepared the mineral artificially.

Minasragrite. W. T. Schaller, 1915. Journ. Washington Acad. Sci., vol. v, p. 7; Third Appendix to 6th edit. of Dana's System of Mineralogy, p. 51. A hydrated acid vanadyl sulphate, $(V_2O_2)H_2(SO_4)_3 \cdot 15H_2O$, probably monoclinic, occurring as a blue efflorescence on patronite at Minasragra, Peru.

Naphtolithe. P. Barbier, 1911. Bull. Soc. Hist. Nat. Autun, vol. xxiv, p. 115. A. Lacroix, Minéralogie de la France, 1913, vol. v, p. 24. A bituminous shale from Thelots, Saône-et-Loire.

Natromontebrasite. F. Gonnard, 1913. Bull. Soc. franç. Min., vol. xxxvi, p. 120. To replace the name Natramblygonite or Natronamblygonit of W. T. Schaller (1911; sixth list), since the mineral is a hydrofluophosphate rather than a fluophosphate. *See* Fremontite.

Nauruite. C. Elschner, 1913. Corallogene Phosphat-Inseln Austral-Oceaniens und ihre Produkte, Lübeck, 1913, p. 54 (Nauruit). A resinous, colloidal calcium phosphate, probably $3Ca_3P_2O_8 \cdot Ca(OH,F)_2$, encrusting the phosphate rock of Nauru or Pleasant Island, in the Pacific. Evidently a kind of phosphorite.

Nephediewit. (Chem. Zentralblatt, 1913, vol. ii, p. 1250. Fortschritte Min. Krist. Petr., 1914, vol. iv, p. 167.) Error for nefedieffite, nefedevite, нефедьевитъ (P. Puzuirevskij, 1872).

Nickelspeise. *See* Placodine.

Oxide-meionite. L. H. Borgström, 1914. *See* Carbonate-marialite.

Oxydhydratmarialith and **Oxydhydratmejonit.** R. Brauns, 1915. *See* Carbonate-marialite.

Pascoite. W. F. Hillebrand, H. E. Merwin, and F. E. Wright, 1914. Proc. Amer. Phil. Soc., vol. liii, p. 49; Zeits. Kryst. Min., vol. liv, p. 209. A monoclinic (?), hydrous vanadate of calcium, $2CaO \cdot 3V_2O_5 \cdot 11(?)H_2O$, occurring as an orange-yellow, powdery efflorescence on vanadium ores at Minasragra, Cerro de Pasco, Peru. Named from the locality.

Pintadoite. F. L. Hess and W. T. Schaller, 1914. Journ. Washington Acad. Sci., vol. iv, p. 576. A hydrous vanadate of calcium, $2CaO \cdot V_2O_5 \cdot 9H_2O$, occurring as a thin, green efflorescence on sandstone at Cañon Pintado, San Juan Co., Utah. Named from the locality.

Placodine. A. Breithaupt, 1841. Ann. Phys. Chem. (Poggendorff), vol. liii, p. 631 (Plakodin, Placodinus niccoleus). A nickel arsenide

described as tabular (πλἄκώδης) crystals from the Jungfer mine, Müsen, Westphalia, but afterwards considered to be an artificial *Nickelspeise*. (For history and literature see C. Hintze, Handbuch der Mineralogie, 1900, vol. i, p. 621.) A. Rosati (Atti (Rend.) Accad. Lincei, Roma, 1913, ser. 3, vol. xxii, sem. 2, p. 243; Zeits. Kryst. Min., 1914, vol. liii, p. 389) proves it to be identical with the recently-described mineral maucherite, tetragonal Ni_3As_2 (F. Grünling, 1913; sixth list). *See* Temiskamite.

Potassio-carnotite. *See* Kalio-carnotite.

Pseudo-eucryptite. F. M. Jaeger and A. Šimek, 1914. [Verslagen k. Akad. Wetensch. Amsterdam, Wis- en Natuurk. Afd., vol. xxiii]; abstract in Neues Jahrb. Min., 1915, vol. ii, Ref. p. 146 (*pseudo-* or *β-Eukryptit*); Proc. Roy. Acad. Sci. Amsterdam, vol. xvii, p. 242. An artificial form of $LiAlSiO_4$ dimorphous with eucryptite.

Pseudowollastonite. In fourth list incorrectly attributed to E. T. Allen and W. P. White, 1906; apparently first used by A. Lacroix, Minéralogie de la France, 1895, vol. i, p. 624 (pseudowollastonite); 1910, vol. iv, p. 777 (pseudo-wollastonite). The artificially-produced, pseudo-hexagonal calcium metasilicate dimorphous with wollastonite. Earlier called *Bourgeoisite* (R. Breñosa, 1885; third list). C. Doelter, Handbuch der Mineralchemie, 1913, vol. ii, p. 250, refers to it as *β-Wollastonite*, in preference to α-Wollastonite of other authors, since it is the modification stable at the higher temperature.

Pyritogelit. *See* Diasporogelite.

Pyroxmangite. W. E. Ford and W. M. Bradley, 1913. Amer. Journ. Sci., ser. 4, vol. xxxvi, p. 169; Zeits. Kryst. Min., vol. liii, p. 225. A triclinic manganese pyroxene, $(Fe,Mn)SiO_3$, found as brown cleavage masses in South Carolina. Alters to Skemmatite (q. v.).

Roscherite. F. Slavík, 1914. [Memoirs Bohemian Acad. Sci.]; Doelter's Handbuch der Mineralchemie, vol. iii, p. 499; Bull. Soc. franç. Min., vol. xxxvii, p. 162. Dark-brown, monoclinic crystals occurring with ježekite, lacroixite (q. v.), and childrenite in drusy cavities in lithionite-granite at Greifenstein, near Ehrenfriedersdorf, Saxony. It is a hydrated basic phosphate of aluminium, manganese, calcium, and iron, $(Mn,Ca,Fe)_2.Al(OH)P_2O_8.2H_2O$. Named after Mr. Walter Roscher, apothecary and mineral collector, of Ehrenfriedersdorf.

Rubidium-microcline. V. I. Vernadsky, 1913. Bull. Soc. franç. Min., vol. xxxvi, p. 263 (microcline rubidifère, Rubidiummikroklin, rubidievyj mikroklin). The microcline (Amazon-stone) of the Ilmen Mountains, Urals, was found to contain 3·12 per cent. of rubidium oxide corresponding to 10·89 per cent. of the silicate $RbAlSi_3O_8$.

Schaumopal. O. Hauser, 1911. Centralblatt Min., 1911, p. 436. A German name for porous opal. Synonym of Float-stone (Ger. Schwimmstein).

Searlesite. E. S. Larsen and W. B. Hicks, 1914. Journ. Washington Acad. Sci., vol. iv, p. 397; Amer. Journ. Sci., ser. 4, vol. xxxviii, p. 437. A hydrated borosilicate of sodium, $NaB(SiO_3)_2 . H_2O$, occurring as small white spherulites (probably monoclinic) in clay at Searles Lake, San Bernardino Co., California. Named after Mr. John W. Searles, pioneer at this locality.

Serpentite. (C. U. Shepard, Contributions to Mineralogy, Amherst College, 1877.) Variant of Serpentine.

Shattuckite. W. T. Schaller, 1915. Journ. Washington Acad. Sci., vol. v, p. 7; Third Appendix to 6th edit. of Dana's System of Mineralogy, p. 72. A massive, fibrous, blue hydrated silicate of copper, $2CuSiO_3 . H_2O$. From the Shattuck Arizona Copper Company's mine at Bisbee, Arizona. *See* Bisbeeite.

Silvialite. R. Brauns, 1914. Neues Jahrb. Min., Beil.-Bd. xxxix (Festschrift Max Bauer), p. 121; Neues Jahrb. Min., 1915, vol. ii, Ref. p. 141 (*Silvialith*). In the Third Appendix to 6th edit. of Dana's System of Mineralogy (1915, p. 70) the name is spelt *Sylvialite*. A hypothetical molecule of the scapolite group, identical with L. H. Borgström's Sulphate-meionite, $CaSO_4 . 3CaAl_2Si_2O_8$. *See* Carbonate-marialite. Named after Dr. (Mrs.) Silvia Hillebrand, of Vienna, daughter of Gustav Tschermak.

Skemmatite. W. E. Ford and W. M. Bradley, 1913. Amer. Journ. Sci., ser. 4, vol. xxxvi, p. 169; Zeits. Kryst. Min., vol. liii, p. 225. Hydrated oxide of manganese and iron, $3MnO_2 . 2Fe_2O_3 . 6H_2O$, occurring as a black alteration product of pyroxmangite (q. v.). Named from *σκέμμα*, a question, because of the doubt whether the mineral really represents a distinct species.

Speziaite. L. Colomba, 1914. Atti Accad. Sci. Torino, vol. xlix, p. 625. A member of the amphibole group occurring as dark-green

fibres and acicular (monoclinic) crystals at Traversella, Piedmont, and with the ortho-silicate formula $5Fe'''_4(SiO_4)_3 + 12(Ca,Mg,Fe'',Na_2H_2)_2SiO_4$. Named after the late Professor Giorgio Spezia (1842–1911), of Turin.

Stibiobismuthinite. G. A. Koenig, Journ. Acad. Nat. Sci. Philadelphia, ser. 2, vol. xv, p. 424. Large, cleavable prisms resembling stibnite rather than bismuthinite in appearance, from Nacozari, Sonora, Mexico, consisting of bismuth sulphide with Sb 8·12 per cent.; formula $(Bi,Sb)_4S_7$. *See* Aurobismuthinite.

Stibiocolumbite. W. T. Schaller, 1915. Third Appendix to 6th edit. of Dana's System of Mineralogy, p. 74. Name proposed for the 'stibiotantalite' from Mesa Grande, California, described by S. L. Penfield and W. E. Ford (1906), because [in one analysis, cf. W. E. Ford, Amer. Journ. Sci., 1911, vol. xxxii, p. 287] the amount of niobium (columbium) is greatly in excess of the tantalum.

Sulphate-mariâlite and **Sulphate-meionite.** L. H. Borgström, 1914. *See* Carbonate-mariâlite.

Sulphate-scapolite. R. Brauns, 1914. Neues Jahrb. Min., Beil.-Bd. xxxix (Festschrift Max Bauer), pp. 83, 120 (Sulfatskapolith). Also named Silvialite (q. v.).

Sylvialite. *See* Silvialite.

Tartarkaite. (Third Appendix to 6th edit. of Dana's System of Mineralogy, 1915, p. 76.) Error for Tatarkaite (q. v.).

Tatarkaite. A. Meister, 1910. Explorations géologiques dans les régions aurifères de la Sibérie, Région aurifère d'Iénisséi, Livraison IX, 1910, p. 498 (татаркаить); abstract in Zeits. Kryst. Min., 1914, vol. liii, p. 597 (Tatarkait). A hydrated silicate of aluminium, magnesium, &c., $R_2O \cdot 11RO \cdot 13R_2O_3 \cdot 30SiO_2 \cdot 19H_2O$, occurring as dark-grey, elongated plates (optically uniaxial and positive) in metamorphosed limestone near the Tatarka river, a tributary of the Angara, Siberia. *See* Angaralite.

Temiskamite. T. L. Walker, 1914. Amer. Journ. Sci., ser. 4, vol. xxxvii, p. 170. A nickel arsenide, Ni_4As_3, occurring as silver-white, radially-fibrous masses in the Temiskaming district, Ontario. According to C. Palmer (Economic Geology, 1914, vol. ix, p. 671; Chem. News, 1915, vol. cxi, p. 219; Zeits. Kryst. Min., 1915, vol. liv, p. 437) it is identical with maucherite. *See* Placodine.

Thanite. M. Rózsa, 1914. Zeits. Anorg. Chem., vol. lxxxviii, p. 328 (Thanit; *Hartsalzkainitit*), p. 332 (*Halitkainit*). A mixture of kainite and halite occurring in the salt deposits of the Werra district, Prussia. Named after the late Professor Karl von Than.

Toryanit. (Rozpr. Akad. Kraków, 1911, vol. xi, ser. A, p. 475; Bull. Intern. Acad. Cracovie, 1911, ser. A, p. 558.) A Polish form of Thorianite (W. R. Dunstan, 1904; fourth list).

Uranospathite. A. F. Hallimond, 1915. Mineralogical Magazine, vol. xvii, p. 221. A yellow or pale-green 'uranium-mica' from Redruth, Cornwall, hitherto classed as autunite. It is orthorhombic (pseudo-tetragonal), with the form of thin, rectangular plates; and is probably a hydrated uranyl salt. Named from uranium and $\sigma\pi\acute{\alpha}\theta\eta$, a broad blade. Compare Bassetite.

Ussingite. O. B. Bøggild, 1914. Meddelelser om Grønland, vol. li, p. 103; Zeits. Kryst. Min., vol. liv, p. 120 (Ussingit). A reddish-violet mineral from the pegmatite veins in the naujaite (sodalite-syenite) at Kangerdluarsuk, Greenland. It is a silicate, $HNa_2Al(SiO_3)_3$, showing certain relations to the zeolites. Triclinic, with one perfect and two poor cleavages. Named after the late Professor Niels Viggo Ussing (1864–1911), of Copenhagen.

Uvanite. F. L. Hess and W. T. Schaller, 1914. Journ. Washington Acad. Sci., vol. iv, p. 576; Third Appendix to 6th edit. of Dana's System of Mineralogy, 1915, p. 81. An orthorhombic, hydrous vanadate of uranium, $2UO_3 . 3V_2O_5 . 15H_2O$, occurring as a brownish-yellow powder disseminated in sandstone in Utah. The name is a contraction of the words uranium and vanadium with the termination *ite*.

Vegasite. A. Knopf, 1915. Journ. Washington Acad. Sci., vol. v, p. 501. A hydrated lead ferric sulphate, $PbO . 3Fe_2O_3 . 3SO_3 . 6H_2O$, differing slightly from plumbojarosite ($PbO . 3Fe_2O_3 . 4SO_4 . 6H_2O$, W. F. Hillebrand and S. L. Penfield, 1902; third list) in composition and optical characters. Occurs as straw-yellow, ochreous masses, consisting of minute fibres and six-sided plates (optically uniaxial), in Clark Co., Nevada. Named from Las Vegas, the principal town of the county.

Velardeñite. W. T. Schaller, 1914. Journ. Washington Acad. Sci., vol. iv, p. 355; Third Appendix to 6th edit. of Dana's System of Mineralogy, 1915, p. 82. A member of the melilite group with the composition $2CaO . Al_2O_3 . SiO_2$. It has been produced artificially, and this molecule occurs in large amount in 'gehlenite' from the Velardeña mining district, Mexico.

Vendeennite. A. E. A. Rivière, 1840. Compt. Rend. Acad. Sci. Paris, vol. xi, p. 208. A. Lacroix, Minéralogie de la France, 1910, vol. iv, p. 640 (vendéennite). A fossil resin from the coal-measures of Vendée.

Wetherilite. (A. Danby, Natural Rock Asphalts, London, 1913, p. 5.) A difficultly fusible bitumen from Canada.

Wetherillite. W. S. Ward in MS., quoted by W. E. Ford and W. M. Bradley, Zeits. Kryst. Min., 1913, vol. liii, p. 219 (Wetherillit). Synonym of hetaerolite and wolftonite (sixth list). Named after the late Mr. W. C. Wetherill.

Wilkeite. A. S. Eakle and A. F. Rogers, 1914. Amer. Journ. Sci., ser. 4, vol. xxxvii, p. 262. A member of the apatite group containing calcium silicate, sulphate, carbonate, and oxide in addition to phosphate, $3Ca_3(PO_4)_2 . CaCO_3 + 3Ca_3(SiO_4)(SO_4) . CaO$; occurring as pink, hexagonal crystals in blue crystalline limestone in Riverside Co., California. Named after Mr. R. M. Wilke, a mineral collector and dealer, of Palo Alto, California.

β-Wollastonite. *See* Pseudowollastonite.

Yukonite. J. B. Tyrrell and R. P. D. Graham, 1913. Trans. Roy. Soc. Canada, ser. 3, vol. vii, sect. 4, p. 13. A brownish-black, resinous, amorphous mineral, resembling pitticite in appearance, consisting of hydrous arsenate of calcium and ferric iron, $(Ca_3,Fe'''_2)As_2O_8 . Fe'''_2(OH)_6 . 5H_2O$. Named after the locality, Yukon, Canada.

Zillerite. (A. Fersmann, Rozpr. České Akad., 1912, vol. xxi, no. 15, p. 2; Bull. Internat. Acad. Sci. Prague, 1912, vol. xvii, p. 118 (Zillerit).) A variant of zillerthite (J. C. Delamétherie, 1795). The name is here applied to the matted-fibrous asbestos (mountain-cork) belonging to the species tremolite-actinolite.

Zinc-dibraunite. K. Nenadkevič, 1911. Trav. Mus. Géol. Pierre le Grand, Acad. Sci. St.-Pétersbourg, vol. v, p. 37 (Цинкдибраунить); abstract in Zeits. Kryst. Min., 1914, vol. liii, p. 609 (Zinkdibraunit). A soft, earthy, chocolate-coloured mineral occurring in cavities in calamine ores at Olkush, Russia. Composition $ZnO . 2MnO_2 . 2H_2O$; this being a salt of a meta-manganese acid is called a braunite, whilst salts of the ortho-acid are called manganites. There is here some confusion between chemical and mineralogical names.

SYSTEMATIC CLASSIFICATION OF NEW MINERALS.[1]

Sulphides, &c.

Temiskamite, Ni_4As_3.
Cobaltnickelpyrite, $(Fe,Ni,Co)S_2$.
Empressite, AgTe.
Aurobismuthinite, var. of bismuthinite.
Stibiobismuthinite, var. of bismuthinite.

Sulpho-salts.

Fizelyite, $5PbS . Ag_2S . 4Sb_2S_3$.

Haloids.

Cerfluorite, $(Ca_3,Ce_2)F_6$.

Oxides.

Lechatelierite, SiO_2.
Skemmatite, $2Fe_2O_3 . 3MnO_2 . 6H_2O$.
Zinc-dibraunite, $ZnO . 2MnO_2 . 2H_2O$.

Carbonates.

Bütschliite, $CaCO_3$.

Sulphates.

Bilinite, $Fe''Fe'''_2S_4O_{16} . 24H_2O$.
Minasragrite, $(V_2O_2)H_2(SO_4)_3 . 15H_2O$.
Vegasite, $PbO . 3Fe_2O_3 . 3SO_3 . 6H_2O$.

Molybdates.

Koechlinite, $Bi_2O_3 . MoO_3$.
Chillagite, $PbMoO_4 . PbWO_4$.
Ferrimolybdite, $2Fe_2O_3 . 7MoO_3 . 19H_2O$.

Borates.

Inyoite, $2CaO . 3B_2O_3 . 13H_2O$.
Meyerhofferite, $2CaO . 3B_2O_3 . 7H_2O$.

Phosphates, Arsenates.

Wilkeite { $3Ca_3(PO_4)_2 . CaCO_3$. / $3Ca_3(SiO_4)(SO_4) . CaO$.
Nauruite, var. of phosphorite.
Fremontite } = Natramblygonite.
Natromontebrasite }
Lucinite, $Al_2O_3 . P_2O_5 . 4H_2O$.
Ježekite, $Na_4CaAl(AlO)P_2O_8F_2(OH)_2$.
Lacroixite, $3AlPO_4 . 4(Ca,Mn)O . 4Na(F,OH) . 2H_2O$.
Roscherite, $(Mn,Ca,Fe)_2 . Al(OH)P_2O_8 . 2H_2O$.
Barthite, $3ZnO . CuO . 3As_2O_5 . 2H_2O$.
Yukonite, $(Ca_3,Fe'''_2)As_2O_8 . Fe'''_2(OH)_6 . 5H_2O$.
Furnacite, chromo-arsenate, Pb,Cu.
Bassetite, $Ca(UO_2)_2(PO_4)_2 . 8H_2O$.
Uranospathite, hyd. phosp. UO_2.

Vanadates.

Hewettite } $CaO . 3V_2O_5 . 9H_2O$.
Metahewettite }
Fernandinite, $CaO . V_2O_4 . 5V_2O_5 . 14H_2O$.
Pascoite, $2CaO . 3V_2O_5 . 11H_2O$.
Pintadoite, $2CaO . V_2O_5 . 9H_2O$.
Uvanite, $2UO_3 . 3V_2O_5 . 15H_2O$.
Hügelite, hyd. vanadate, Pb,Zn.

Silicates.

Rubidium-microcline.
Laneite, var. of amphibole.
Speziaite, var. of amphibole.
Holmquistite (Lithionglaukophan), var. of amphibole.
Pyroxmangite, $(Fe,Mn)SiO_3$.
Bazzite, sil. scandium, &c.
Angaralite, $2MgO . 5(Al,Fe)_2O_3 . 6SiO_2$.

[1] Only the more important names given in the preceding alphabetical list are here included.

Custerite, $Ca_2(OH,F)_2SiO_3$.
Silvialite (Sulphate-meionite), $CaSO_4 . 3CaAl_2Si_2O_8$.
Velardeñite, $Ca_2Al_2SiO_7$.
Grothine, sil. Al,Ca.
Chrome-idocrase, var. of idocrase.
Bisbeeite, $CuSiO_3 . H_2O$.
Shattuckite, $2CuSiO_3 . H_2O$.
Hodgkinsonite, $Zn_2MnSiO_5 . H_2O$.
Ussingite, $HNa_2Al(SiO_3)_3$.
Cebollite, $H_4Al_2Ca_5Si_3O_{16}$.
Deeckeite, $R'_2R''R'''_2(Si_2O_5)_5 . 9H_2O$.
Epidesmine, $Ca_3Al_2Si_6O_{16} . 20H_2O$.
Faratsihite, $(Al,Fe)_2O_3 . 2SiO_2 . 2H_2O$.
Tatarkaite, $R'_2R''_{11}R'''_{13}Si_{30}O_{111} . 19H_2O$.
Ferriallophane, var. of allophane.
Ferroprehnite, var. of prehnite.
α-Chloritite, $4Al_2O_3 . 5SiO_2 . 7H_2O$.
Searlesite, $NaB(SiO_3)_2 . H_2O$.

HYDROCARBONS.

Kundaite.
Naphtolithe.
Vendeennite.
Wetherilite.

OBITUARIES.

John Jacob Beringer (1857–1915) was born at Penzance and educated at Redruth. He entered the Royal School of Mines as a Royal Exhibitioner, taking the Associateship in 1880. In 1881 he was assistant in chemistry and assaying at King's College, London, and from 1882–91 lecturer to the Miners' Association of Cornwall and Devonshire, and public analyst for the County of Cornwall. From 1892 until his death he was Principal of the Camborne School of Mines, where he had great success as a teacher. His 'Textbook of Assaying' is a standard work, and has passed through thirteen editions. He was a member of our Society since 1894. His death, on March 28, 1915, had been hastened by overwork, and by the loss of the sight of one eye due to too close application to the microscope.

Sir Arthur Herbert Church (1834–1915) was born, the fourth son of a solicitor, in London, on June 2, 1834, and educated at King's College, London, the Royal College of Chemistry, and Lincoln College, Oxford. He was Professor of Chemistry in the Royal Agricultural College at Cirencester (1863–79), lecturer in organic chemistry at Cooper's Hill College (1888–1900), and Professor of Chemistry in the Royal Academy of Arts, London (1879–1911). He was the author of several handbooks, some of which were prepared in connexion with the collections in the Victoria and Albert Museum. These dealt with a variety of subjects, and passed through many editions: 'Laboratory Guide for Agricultural Students' (1864, 9th edit. 1912), 'Precious Stones' (1882, several editions and reprints to 1913), 'English Earthenware' (1884), 'English Porcelain' (1885), 'Food Grains of India' (1886), 'Chemistry of Paints and Painting' (1890, 4th edit. 1915), and several other works. His scientific papers were also considerable in number and covered a wide range of subjects: the Royal Society Catalogue quotes 137 titles up to the year 1900. Several of them dealt with mineralogy, more especially with the analysis of Cornish minerals. He described as new species: bayldonite, botallackite, namaqualite, pelagite, restormelite, tallingite, tasmanite, and woodwardite; and also the rare hydrous cerium phosphate which bears his name—churchite.

Some of his papers appeared in the pages of this Magazine. He was an original (1876) member of this Society and a past President (1898–1901). He was elected a fellow of the Chemical Society as long ago as 1853, and of the Royal Society in 1888, and was created K.C.V.O. in 1909. He was D.Sc. of Oxford, and a fellow of King's College, London.

Sir Arthur Church had a private laboratory at his home at Kew Gardens, and he was an enthusiastic collector of objects of art of various kinds. He bequeathed his chemical and mineralogical apparatus and mineral specimens, together with a sum of £100 for the purchase of apparatus and specimens, to the Mineralogical Department at Oxford. His valuable collection of faceted gem-stones has, in accordance with a wish expressed in his will, been presented by his widow to the trustees of the British Museum, and is now on exhibition in the recent addition case in the mineral gallery of the Natural History Museum at South Kensington. This collection comprises about 200 choice and selected stones, most of them being mounted in gold rings. The sixty-nine examples of zircon display a wide range in colour and include two stones of a bright sky-blue. Of his many-sided activities mention should also be made of the assistance he gave in the preservation of the mural paintings and stonework of the Houses of Parliament and Westminster Abbey. He died on May 31, 1915.

Carl Hermann Credner (1841–1913) was, since 1872, Director of the Geological Survey of Saxony and Professor of Geology of the University of Leipzig. In the same year he published his 'Elemente der Geologie', which passed through ten editions. Some of his writings dealt with petrology and mineral-deposits.

Orville Adelbert Derby (1851–1915) was born at Kelloggsville, New York, and graduated at Cornell University, Ithaca, New York, where in 1873 he was instructor in geology. In 1876 he was appointed assistant on the 'Commissão Geologica do Brazil', and in 1879 director of the geological section of the 'Commissão Geographica e Geologica do Estado de São Paulo'. More recently, in 1906, he became director of the newly established 'Serviço Geologico e Mineralogico do Brazil' at Rio de Janeiro. He was the author of numerous papers on Brazilian geology, and on the deposits of gold, diamonds, and monazite-sands in that country. A note on 'Monazite and xenotime in European rocks' appeared in this Magazine (1897, vol. xi, p. 304). His papers on the

nepheline rocks of Brazil appeared in the Quarterly Journal of the Geological Society, of which society he was a fellow since 1884. The Brazilian mineral derbylite, named after him, was described in this Magazine (1897, vol. xi, p. 176).

James Geikie (1839–1915) was an original (1876) member of the Mineralogical Society. He joined the Scottish Geological Survey in 1861, and since 1882 was Professor of Geology and Mineralogy in the University of Edinburgh.

Rolf Görgey von Görgö (1886–1915) was an assistant in the Mineralogical and Petrographical Institute of the University of Vienna. Although a Hungarian, he acted as a company-commander in a Tyrolese regiment, and fell at Rudnik on the San in Galicia on May 25, 1915. Dr. R. Görgey had published several mineralogical papers, dealing more especially with zeolites and the minerals of salt-deposits. In 1907, in company with F. Cornu, he visited the zeolite localities of the Faroe Islands and of Scotland and wrote 'Ein Beitrag zur topographischen Mineralogie der Färöer' (1910). A detailed description of the newly-discovered deposits of potash-salts at Wittelsheim in Upper Alsace was given by him in 1912.

Constantin Guillemain (1873–1914) was born and educated at Breslau in Silesia. In his inaugural dissertation (Breslau, 1898) he gave the results of a large number of analyses of mineral sulpho-salts. He wrote on the geology and ore-deposits of Cameroon, Katanga, and Uruguay, and was a Privatdozent for geology and geography in the Technical High School at Aachen. He was a victim of the war.

Sir Walter Noel Hartley (1846–1913), since 1879 Professor of Chemistry in the Royal College of Science, Dublin, was best known by his researches in spectroscopy. He applied these methods to the spectrographic analyses of ores, minerals, and meteorites. The Kangra Valley (India) meteorite was described by him, and he afterwards presented the stone to the British Museum collection of meteorites.

Adolf von Koenen (1837–1915), since 1881 Professor of Geology at Göttingen, and previously at Marburg. Most of his work was palaeontological and geological, but in 1874 and 1877 he gave descriptions of the zeolite occurrence on Mt. Stempel near Marburg. The mineral koenenite was named after him by F. Rinne in 1902.

Herbert Kynaston (1864–1915), since 1903 Director of the Geological Survey of the Transvaal and later of that of the Union of South Africa, was previously attached to the Scottish Geological Survey. Some of his work was petrographical, and he examined ore-deposits in the Transvaal. He died on June 29, 1915, at Pretoria, after an operation for appendicitis.

Henry James Johnston Lavis (1856–1914) early took an interest in geology and became a fellow of the Geological Society while he was a medical student at University College, London. He went to Naples in 1879 as a medical practitioner, remaining there until 1894. Here he made a detailed study of Vesuvius and other Italian volcanoes, and became Professor of Vulcanology in the University at Naples. His study of vulcanology merged into that of the petrology of igneous rocks. After leaving Naples he settled in France as a hospital physician. He met his death in a motor-car accident on September 10, 1914, while escaping from the German invasion. In 1912 he issued a bibliography of his publications, giving 161 titles; curiously, this does not mention his paper on a new Vesuvian mineral—chlormanganokalite, which appeared in this Magazine (1908, vol. xv, p. 54).

Charles Richard Lindsey (–1914) was a member of this Society since 1886, and he contributed a paper on 'Brookite in the Cleveland ironstone' to this Magazine in 1905. Being an Associate of Owens College, he received the degree of B.Sc. (Vict.) under the Charter of 1880. At one time he was honorary secretary of the Manchester Geological Society. His business as a chemical manufacturer gave him an opportunity of forming a collection of economic minerals.

Siegfried Martius (–1914) was assistant in the Mineralogical Institute of the University of Bonn. His dissertation for the degree of doctor (Bonn, 1911) discussed the origin of the white pumiceous tuffs and trass of the Laacher See district. He also described occurrences in situ of nephrite in the southern Apennines (Abstract in Journ. Chem. Soc., 1915, ii, 360). He was killed in the war on October 23, 1914.

Hugo Heinrich Wilhelm Müller (1833–1915), a past-President of this Society, was born on July 29, 1833, at Tirschenreuth in Bavaria. He studied chemistry at Leipzig and Göttingen, graduating at the latter university in 1853. For a time he acted as assistant to Liebig at Munich, and it was on the recommendation of Liebig that he came to England in 1854 as an assistant to Warren De la Rue. He later

ntered the firm of stationers and paper-makers, De la Rue & Co., aving charge of the postage-stamp branch, becoming a partner in 1873, nd retiring in 1902. Much of his scientific work was done in collabo- ation with Warren De la Rue, and more recently he worked regularly n the Davy-Faraday research laboratory of the Royal Institution. He arly took an interest in mineralogy, his first papers, in 1852 and 1853, e.ing on the minerals found in the neighbourhood of his birth-place, and n the preparation of lithia from the Bavarian triphylite. In 1859 he ublished in the Journal of the Chemical Society mineralogical notes n cinnabar pseudomorphs from Spain, libethenite from Congo, columbite om Greenland, and the meteoric iron of Zacatecas, Mexico. Most of s work, however, had reference to organic chemistry, more especially f substances of vegetable origin, and he always endeavoured to obtain hese substances in a form suitable for crystallographic determination. He also made a study of vegetable fibres in connexion with their daptability to paper-making.

Dr. Hugo Müller was a prominent member and frequent attendant of everal scientific societies. He was elected a Fellow of the Royal Society in 1866, and was president of the Chemical Society (1885–7), nd of the Mineralogical Society (1901–4). He was a member of the Crystallological Society, which in 1883 was amalgamated with the Mineralogical Society. The honorary degrees of LL.D. (St. Andrews) nd D.Sc. (Manchester) were conferred on him. At the time of his marriage with an English lady in 1878 he became a naturalized British ubject. He died on May 23, 1915, at his country house at Camberley n Surrey, where he had established a beautiful garden. His collection f minerals, numbering some two thousand good specimens, has been resented by his widow to the University Museum at Oxford.

Leopold Oppenheimer (–1914) was a demonstrator under Prof. E. A. Wülfing at Heidelberg. His dissertation (Heidelberg, 1914; bstract in Journ. Chem. Soc., 1915, ii, 644) gave the results of detailed ptical determinations made on carefully analysed specimens of cordierite rom several localities. He was killed in Belgium on August 22, 1914.

Albert de Romeu (1875–1915) was Professor of Mineralogy and Geology in the École centrale des Arts et Manufactures in Paris. He vas the first member (elected in 1903) of the French Mineralogical Society to fall in the European war. As a lieutenant of the reserve n the heavy artillery he was killed on January 12, 1915, at Bucy-le-Long on the Aisne. He had done petrographical work in Lacroix's

laboratory at the Natural History Museum in Paris, and had charge of the mineralogical section of the colonial laboratory of the museum. He made a special study of metalliferous deposits, visiting those of France, Canada, United States, and Congo, and had accumulated material for the preparation of a treatise on this subject. An obituary notice by Prof. A. Lacroix has been given in Bull. Soc. franç. Min., 1915, vol. xxxviii, pp. 32–34.

The Right Hon. Sir Henry Enfield Roscoe (1833–1915), the celebrated chemist, claims also the attention of mineralogists. In connexion with his classical researches on vanadium he discovered in 1876 a vanadate of lead and copper, which he named mottramite, amongst the copper-ores of Alderley Edge and Mottram St. Andrew in Cheshire. In the same paper he also gave his results of an analysis made on a vanadium-mica which had recently been discovered in California and named roscoelite.

Frederick William Rudler (1840–1915) was born in London on July 8, 1840, being the son of a schoolmaster. He joined the science classes at the Regent Street Polytechnic, and in 1861 was appointed assistant-curator in the Museum of Practical Geology. He left here for a time, 1876–9, to take up the post of lecturer in natural science in the University College of Wales at Aberystwith, returning again in 1879 as curator and librarian, and also (until 1880) as registrar of the Royal School of Mines. Here he did his chief work in forming and arranging the collections and in supplying information to all inquirers; and this was continued for a time after his official retirement in 1902 (when he was awarded the Companionship of the Imperial Service Order—I.S.O.), his very useful 'Handbook to a collection of the minerals of the British Islands' having been published in 1905. His earliest catalogue of the mineral collection dated back to 1864. He also wrote on the collection of British pottery and porcelain which he formed in the same museum.

Although Mr. Rudler had little time or opportunities for original research in mineralogy, yet he possessed a vast store of detailed knowledge relating to mineralogy and geology, more particularly with reference to their practical applications and their connexion with other branches of inquiry; and he was always ready to impart this information to others in a quiet and unassuming manner. His knowledge was indeed encyclopaedic. He commenced writing articles in 1867 for 'Ure's Dictionary of Arts, Manufactures, and Mines', the seventh edition

of which he edited in 1878–9. He wrote a long series of articles for Thorpe's 'Dictionary of Applied Chemistry' (1890–3) and the ninth and eleventh editions of the 'Encyclopaedia Britannica'. He also wrote many articles of a more popular character, and many reviews, and for several years was very successful as a University Extension lecturer on geology. His work in another direction was in connexion with various scientific societies. He was President of the Anthropological Institute, the Geologists' Association, the South-Eastern Union of Scientific Societies, and the Essex Field Club, and vice-President of the Geological Society. He was an original member of the Mineralogical Society and treasurer for a number of years (1891–1901). He died on January 23, 1915, at his residence at Tatsfield, in Surrey. His library and collection of minerals, ethnological objects, &c., have been transferred to the University College of Wales at Aberystwith, where an F. W. Rudler scholarship has been established. Biographical notices with portraits have appeared in 'Man' (Royal Anthropological Institute), 1915, vol. xv, p. 33, and Geological Magazine, 1915, vol. ii, p. 142.

Fritz Seemann (1884–1914) was curator of the mineralogical and geological section in the town museum of Aussig, Bohemia, and had just been appointed Professor of Mineralogy and Geology in the Agricultural Academy at Tetschen as successor to J. E. Hibsch, with whom he was associated in the preparation of the geological map of the Midland Mountains of Bohemia. Some of his papers were descriptive of Bohemian mineral occurrences. He was an early victim of the European war, falling in Serbia on August 16, 1914.

William Semmons (–1915) was at one time a member of this Society, and he contributed five papers to the early volumes of this Magazine, these being descriptive of new occurrences of the copper minerals chrysocolla, brochantite, enargite, and connellite. Being a copper-broker and connected with mining enterprises, he took advantage of his good opportunities for collecting minerals. During the sessions 1878–80 he was President of the Liverpool Geological Society. He died at East Dulwich, London, on October 13, 1915, at the age of 74.

Johannes Karl Theodor Struever (1842–1915), more often known as Giovanni Strüver, was born at Brunswick on January 23, 1842. He studied at Göttingen, and was assistant there to Sartorius von Waltershausen, during which period his published papers dealt with fossil fishes. At the end of 1864 he migrated to Italy, acting first as teacher

of mineralogy and geology in the Engineering School at Turin, and later as Extraordinary Professor in the University of the same city. In 1873 he was appointed Ordinary Professor of Mineralogy and Director of the Mineralogical Institute in the University of Rome, holding this post until his death on February 21, 1915. He was the author of several elaborate crystallographic memoirs on Italian minerals, and in 1868 described sellaite as a new species. His last papers, in 1901, dealt with the chemical action at the ordinary temperatures of mineral sulphides (hauerite and iron-pyrites) on metallic silver and copper. On two occasions, in 1876 and 1907, have minerals been named after him. He was a member of the Lincei Academy, and was elected an honorary member of the Mineralogical Society in 1903. A biographical notice with portrait and a bibliography of fifty-six titles has been given by A. Rosati in Centralblatt Min., 1915, pp. 321–330.

Wirt Tassin (1869–1915). During the period (1893–1909) in which he held the position of chemist and assistant curator of mineralogy in the United States National Museum at Washington, he wrote papers on meteorites and meteoric minerals, as well as various museum catalogues, of which the most useful is a 'Descriptive Catalogue of the Collection of Gems' (1902). Since his retirement from the museum he practised as a consulting metallurgist and chemical engineer.

Newton Horace Winchell (1839–1914) graduated at the University of Michigan in 1866, and was attached to the Geological Surveys of Michigan and of Ohio. From 1872 to 1900 he was State Geologist of Minnesota, and Professor of Geology and Mineralogy in the University of Minnesota at Minneapolis. Since 1905 he was archaeologist to the Minnesota Historical Society. He founded and edited (1888–1905) the 'American Geologist', a journal which was afterwards incorporated in 'Economic Geology'. He was a founder and three times president of the Minnesota Academy of Science. In collaboration with his son A. N. Winchell he wrote 'Elements of optical mineralogy' (1909).

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154	—	*Add* to Bibliography of N. Story-Maskelyne: 1873 (With W. D. Herman.) Ueber die Darstellung und Form von Phosphorkrystallen. Tageblatt d. 46. Versammlung Deutscher Naturf. u. Aerzte in Wiesbaden, p. 128. 1873 (With W. Flight.) Einiges über die Farbe der Diamanten. ibid., pp. 128–129.

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xxxii	6	*For* 16 *read* March 16.
21	2*	*For* 'Mean Quarry' *read* 'Mean'.
33	10*	*For* imilarities *read* similarities.
40	8	*For* lat. 66° 34′ N. *read* lat. 46° 34′ N.
40	19	*For* In the winter of 1910 *read* Early in 1911.
46	13	*For* $OT = a\tan\frac{\theta}{2}$ *read* $OT = a\tan\frac{90°-\theta}{2}$.
		For $OT' = a\cot\frac{\theta}{2}$ *read* $OT' = a\cot\frac{90°-\theta}{2}$.
157	7	*For* $(31\bar{2}1)$ and $(41\bar{3}1)$ *read* $(3\bar{1}21)$ and $(4\bar{1}31)$.
160	10*	*For* $3Ca_3(PO_4)_2.Ca_2(OH)$ *read* $3Ca_3(PO_4)_2.Ca(OH)_2$.

* From bottom of page.